PHYSICS 20

Module 6

Light as a Wave

Distance Learning

Alberta
EDUCATION

Physics 20

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Light as a Wave

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EDUCATION

Distance Learning

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Student Module
Module 6
Light as a Wave
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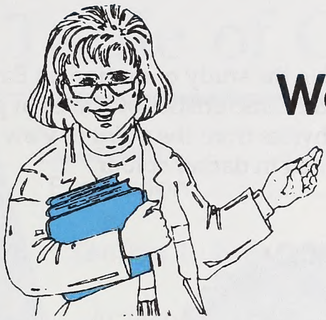
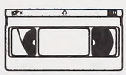


Welcome to Module 6!

We hope you'll enjoy your study of *Light as a Wave.*

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.



You also have the option of viewing laser videodisc clips when you see the bar codes like this one.

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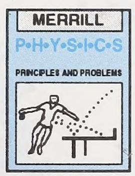
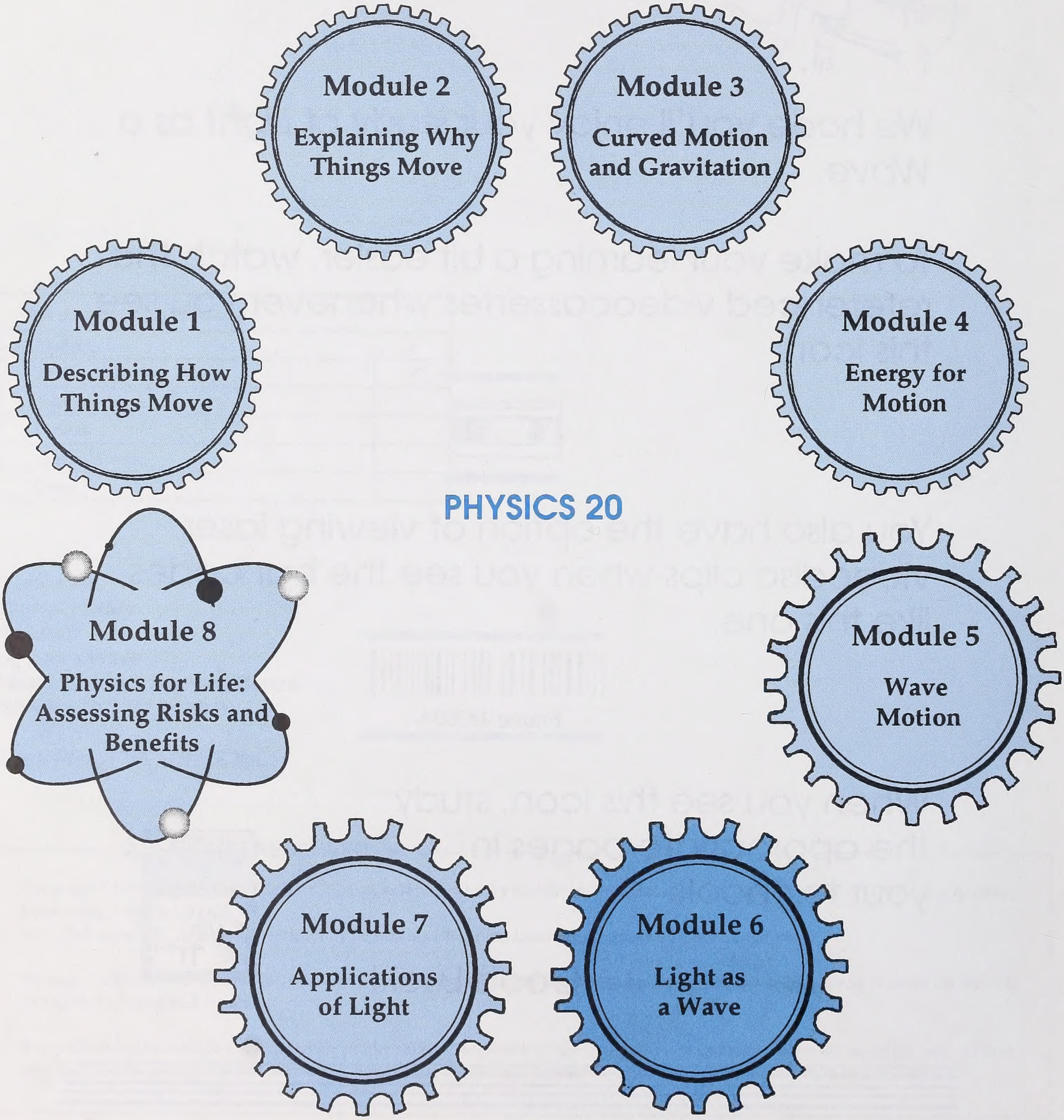
When you see this icon, study the appropriate pages in your textbook.



Good Luck!

Course Overview

This course contains eight modules. The first four modules involve the study of motion on Earth and in the heavens. Modules 5, 6, and 7 investigate the properties and characteristics of waves in general and light waves. The last module is an introduction to nuclear physics from the point of view of risk/benefit analysis. The module you are working in is highlighted in darker colour.



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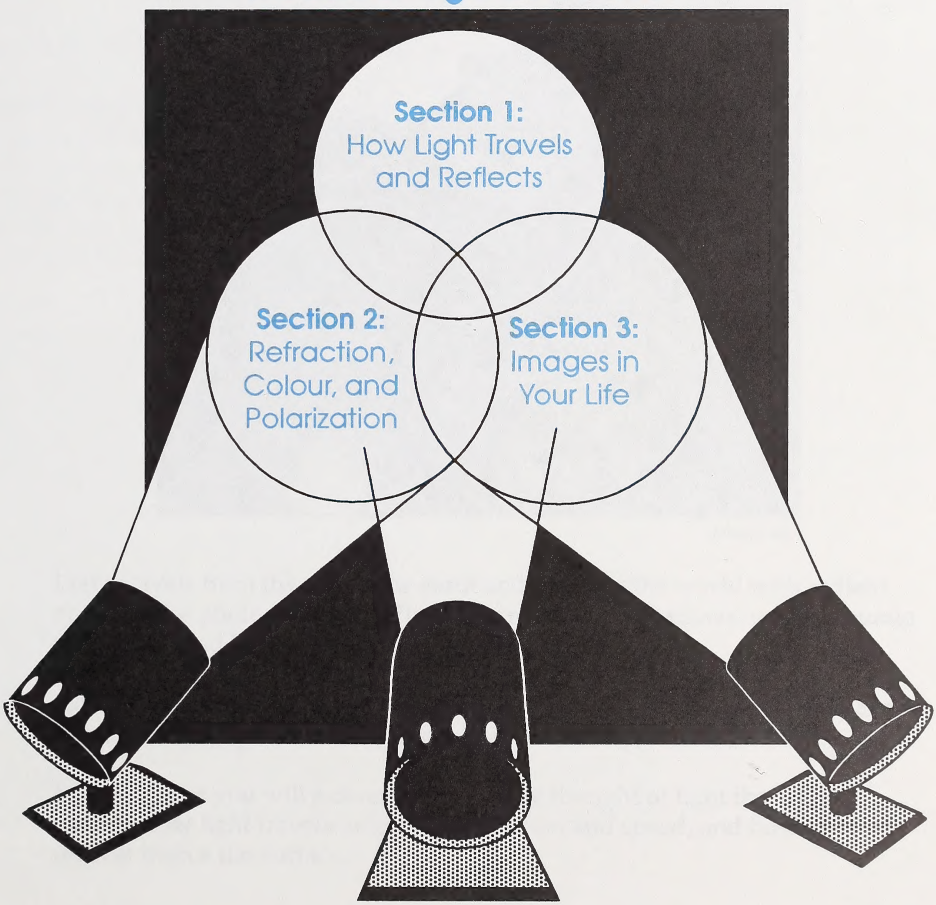
OVERVIEW

In previous science courses you studied the various forms of energy and learned how they could be transformed from one form to another. You also discovered that light is just another form of energy. Can you imagine what life would be like without light energy? Could you see? Could you live?

The basic processes of life depend on light energy and photosynthesis. Your sense of sight and your ability to see colour rely directly on light energy. Light energy also makes you feel good – you usually are in a better mood on a bright and sunny day than on a dark and cloudy day.

In this module you will learn about the properties of light. You will explore the reflection and refraction of light and learn how reflection and refraction apply to your life.

Module 6: Light as a Wave



Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete three section assignments. The mark distribution is as follows:

Section 1 Assignment	35 marks
Section 2 Assignment	43 marks
Section 3 Assignment	22 marks
TOTAL	**100 marks**

Section

1 How Light Travels and Reflects

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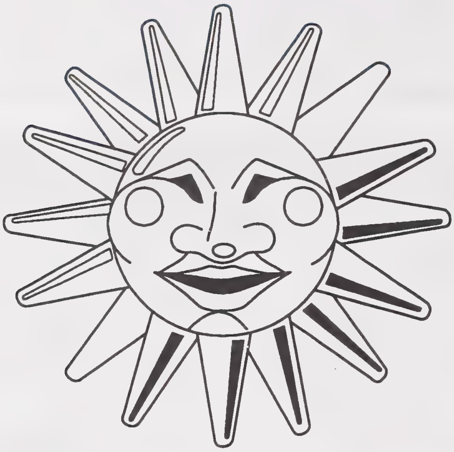
Light travels from the sun to the earth and supplies the world with radiant energy. The photo shows that light can make sharp shadows, create accurate reflections, and light up the world so that you can see.

How do you think light is able to do this? How is light able to travel to Earth through empty space? How are shadows and reflections formed?

In this section you will examine how people thought of light throughout history, how light travels in terms of direction and speed, and how light reflects from a flat surface.

Activity 1: History of Models for Light



The phenomenon of light is so spectacular that it is no wonder that almost all ancient civilizations considered light and the sun to be related to a god.

For one ancient civilization, the name for one of their gods was *Teotl*. The symbol for Teotl was very similar to the symbol shown to the left.

1. Can you name the ancient civilization that worshipped this sun god?

It wasn't until around the fifth century B.C. that a civilization tried to explain light in a rational way. The Greeks were the first to suggest that light is an invisible particle that travels at an infinite speed in a straight line and that this particle can stimulate vision. This theory of light lasted for over 2000 years until the sixteenth century A.D. It was during this period that two famous scientists proposed opposing theories for light.

Particle Theory

Sir Isaac Newton – "Light is a particle called a corpuscle that travels at high speed in a straight line."

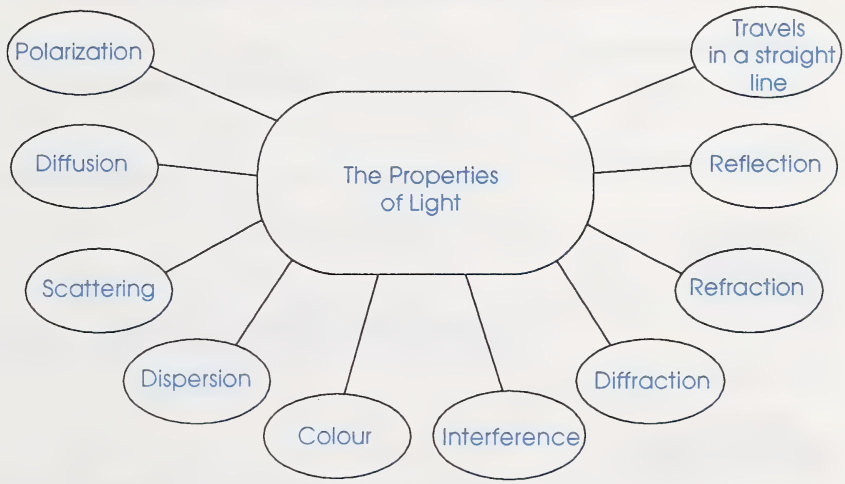
Wave Theory

Christian Huygens – "Light is a wave that travels at high speed in a straight line."

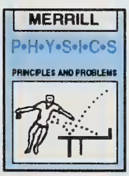
2. These two opposing theories caused a division in the scientific community. Which theory do you think is correct? Does light travel as a wave (like sound) or does it travel as a particle? Justify your answer using any light phenomena you have observed or experienced.

3. The two theories are different, but they appear to have some similarities. Examine the two theories of light and list two ideas that are common to both.

While trying to determine which theory was correct, scientists conducted many varied experiments involving light and identified several properties of light. The following diagram shows these properties.



Many of these properties should be familiar to you from your work in Module 5. Others will be featured in this module and Module 7.



4. Choose the property of light from the previous diagram that best explains the behaviour of light shown in each of the following photographs from the textbook.

   a. Figure 17-1 on page 348

   b. Figure 17-3 on page 349

   c. Figures 19-2 and 19-3 on page 393

   d. Figure 16-10 on page 338

   e. Figure 16-8 on page 337

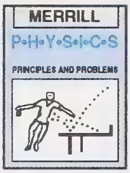
As you work through the rest of this module, you will have an opportunity to investigate these properties. Your observations will help you decide which theory best explains the properties of light.

Check your answers by turning to the Appendix, Section 1: Activity 1.

Activity 2: Propagation: Straight as an Arrow

propagation – the act of travelling from one place to another

One idea that was common to all early theories of light was that light must travel in a straight line. Sometimes this is called straight line **propagation**. Why did the early scientists believe this idea to be true? To answer this question, you will now do an investigation that is similar to Da Vinci's "Camera Obscura Experiment" from the 1500s. You can learn the basic ideas of this experiment by reading the Physics Lab called Pinhole Camera on page 334 of your textbook.



Investigation: Pinhole Camera

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will use observations to learn more about how light travels.

Materials

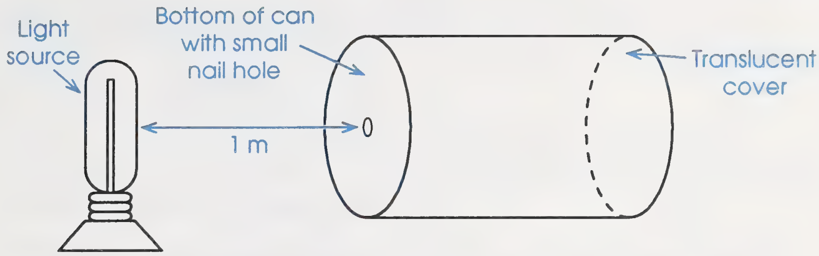
In addition to the materials listed on page 334 of your textbook, you will also need a very dark room.

Procedure

translucent – a property that allows light to pass through a material, but does not permit objects to be clearly seen through the material

- Use the small nail to punch a hole near the centre of the bottom of the coffee can.
- Place the **translucent** cover on the top of the can.
- Turn on the light bulb and turn off all the lights in the room.

- Stand about 1 m from the light bulb and point the hole in the can at the light bulb.



- Observe the pattern or image formed on the translucent cover.

- Slowly move the coffee can away from the light bulb and observe the image on the cover as you move it further away.

Optional Extension

- If you have access to some unexposed photographic film and an interest in photography, you may want to try to use your pinhole camera to take photographs. If this does not interest you, skip ahead to the Observations and Analysis section.

- Your camera will need to be modified by putting a moveable flap in front of the pinhole. You will also need to cover the outside of the translucent lid with an opaque material. The unexposed film will need to be placed on the inside of the cover while in a very dark room. Your camera is now ready to go!

- Since the pinhole is so small, you will need to keep the moveable flap open for at least four seconds to allow enough light in to develop the film. Rest the camera on a large, steady object while you take your picture so that the image is as clear as possible.

- If you are careful not to double expose the film when you remove it from the inside of the lid in a very dark room, you should find that your photographs are recognizable, even if the objects do have a slightly blurry outline.

- Note that the cameras that most people buy commercially use a lens to produce a sharper image from a large opening with much less exposure time.

Observations and Analysis

1. When you were 1 m from the light bulb, an image was formed on the translucent cover. Sketch the image as it first appeared.

2. What is the orientation of the image in relation to the light bulb? Is it right-side-up or vertically reversed (upside down)?

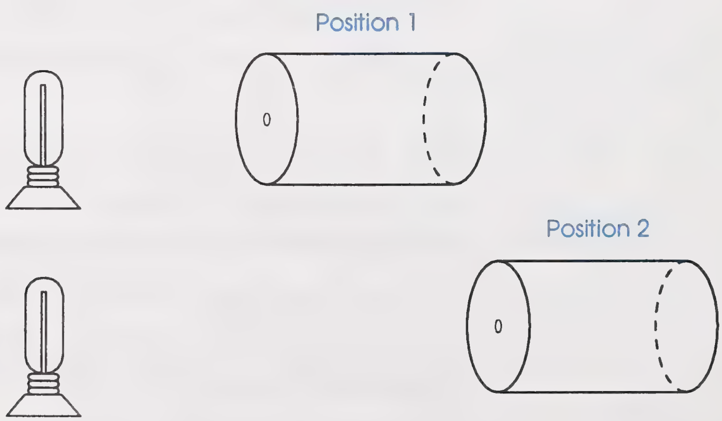
3. On the previous diagram, draw a ray of light from the top of the light bulb, through the nail hole, to the translucent cover. Draw a similar ray from the bottom of the light bulb, through the nail hole, to the cover. Show the direction that the light beam is travelling by drawing arrowheads on the rays.

4. Do the rays that you drew for question 3 explain the orientation of the image? What do they prove?

5. Is the image reversed right to left (horizontally reversed)? How would you design an experiment to prove this?

6. Describe the changes in the image that you observed as you moved the coffee can away from the light source.

7. Use ray diagrams to show why the image gets smaller as the distance between the light bulb and the coffee can increases. Answer by completing the following diagrams.



Conclusion

8. Based on your observations, describe how light travels.

Applications

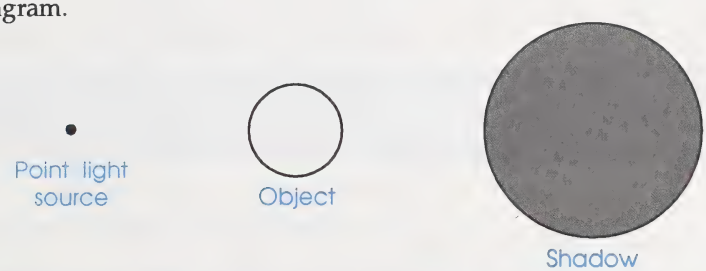
9. Your eye is a type of pinhole camera that uses light beams that come from an object and pass through a tiny opening called the iris. How would you expect images to be formed at the retina on the back of your eye? Explain your answer.

10. This experiment was one of the first experimental proofs that light travels in a straight line. Can you think of any other example that proves that light travels in a straight line?

opaque – a property that does not allow light to pass through a material

You see objects because light is either emitted by an object (a light bulb, the sun, or a fire) or because light is reflected off an opaque object. In all cases, light travels in a straight line from the object to your eye. The fact that you cannot see objects around corners is proof that light travels in a straight line. The fact that every opaque object creates a shadow is also proof that light must travel in a straight line. This fact was reinforced by Newton.

11. Use ray diagrams to show the creation of shadows in the following diagram.

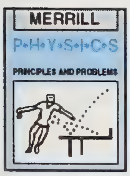


Check your answers by turning to the Appendix, Section 1: Activity 2.

Activity 3: Propagation: Faster than a Speeding Bullet

Another concept that is common to both theories of light is the idea that light must travel at a high speed. When you switch on a light bulb, the light appears to reach your eye instantaneously. But how fast does light actually travel?

The early attempts at determining the speed of light are discussed on pages 331 and 332 in your textbook. Read these pages and then answer the following questions.



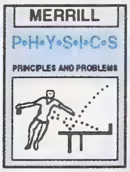
1. Before the seventeenth century A.D., how fast did most people believe light travelled?

2. Who was the first person to suggest that light has a finite speed?

Galileo was the first to suggest a method of determining the speed of light. He proposed to measure the time it took for light to travel a known distance and determine the speed of light using a candle and the most accurate timing device of that time (a water clock or sand clock).

3. Why was Galileo's method unsuccessful at determining a value for the speed of light?

4. How could Galileo's method be improved so that a value for the speed of light could be determined?



Ole Roemer's method was to use celestial distances (distances in space) rather than terrestial distances (distances on Earth). A simplified diagram of his method is shown on page 331 of your textbook.

5. What is the significance of the 22-min time period calculated by Roemer?

6. Roemer collected the data and Huygens calculated the speed of light using $v = \frac{d}{t}$. If the diameter of Earth's orbit was 3.0×10^{11} m and the time for light to travel this distance was 22 min, calculate the value that Huygens would have obtained for the speed of light.

7. The classic attempt at determining the speed of light was done by Michelson in 1926. What value for the speed of light did he obtain?

8. Why did Roemer's method not obtain the same value as Michelson's method?

9. Roemer's method was an example of the needs of technology resulting in scientific advances. Why was Roemer so interested in compiling data about Jupiter's moon, Io?

10. As technology improved, methods of obtaining data improved. What is the modern method of determining the speed of light? Explain the equation used in the calculation.

Since the speed of light in a vacuum is such an important value, it is given its own symbol (c). The value for the speed of light in a vacuum is usually rounded off to 3.00×10^8 m/s for calculations. This value is also used for calculating the speed of light in air.

The universal wave equation is usually written in terms of *c* when dealing with light.

$$\boxed{c = \lambda f}$$

DID YOU KNOW?

If the speed of light is 3.00×10^{8} m/s, it can travel over seven times around the earth in one second.

11. What is the speed of yellow light that has a wavelength of 5.56×10^{-7} m and a frequency of 5.40×10^{14} Hz?

12. The investigation of the propagation of light confirms that light does travel in a straight line and that it does travel at high speed, but can it prove whether light travels as a wave or a particle? Explain.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Activity 4: Reflection from Flat Surfaces

The water on this lake is so still that it is just like a mirror and is able to reflect the surrounding scenery perfectly.

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People who enjoy canoeing usually find the early morning or late evening to be the best time for enjoying perfectly still water. At these times the water is almost perfectly flat and acts very much like a mirror.

The next investigation will allow you to study the behaviour of light during reflection.

Investigation: Law of Reflection

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [ ] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Purpose

In this investigation you will collect observations to help discover how a beam of light behaves when it reflects off a shiny surface.

PATHWAYS

If you have access to laboratory facilities, do Part A. If you do not have access to laboratory facilities, do Part B.

Part A

Materials

Caution

- a laser (Be sure to follow all safety instructions that accompany the laser.)
- a reflecting surface (mirror)
- a protractor
- masking tape

Procedure

- Place the mirror on a smooth surface.
- Tape the protractor to the surface of the mirror so that the protractor is standing on its edge. Check the diagram of the apparatus in the Observations and Analysis section on the next page for the correct setup.

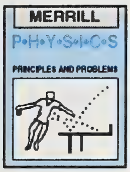
- Direct a laser beam parallel to the protractor, as shown in the diagram in the Observations and Analysis section. The laser beam must strike the mirror at the exact centre of the protractor. If you have difficulty seeing the laser beam, a very fine mist of water from a spray bottle will help show the beam.

1. Draw the reflected beam of the laser on the diagram in the Observations and Analysis section.

End of Part A

Part B

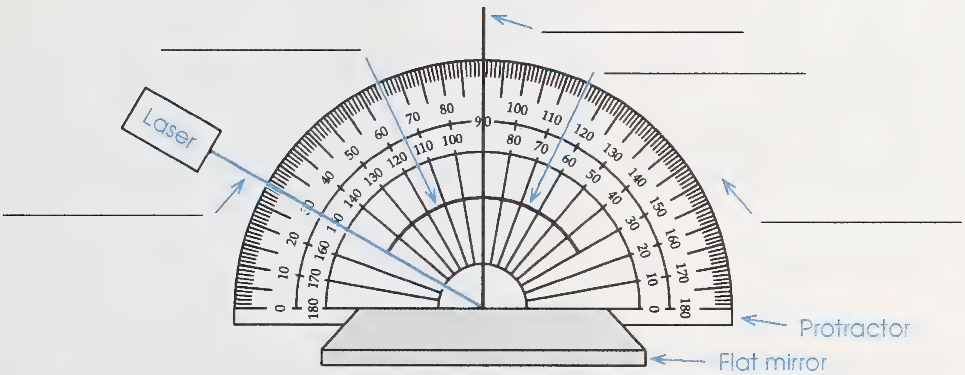
Procedure



2. Study Figure 17-1 on page 348 of your textbook. Draw what you see in the textbook on the diagram in the Observations and Analysis section.

End of Part B

Observations and Analysis



3. Label the following things in the spaces provided on the previous diagram.

- normal
- incident ray
- reflected ray
- angle of incidence (θ_i) (measured from the normal to the incident ray)
- angle of reflection (θ_r) (measured from the normal to the reflected ray)

normal – an imaginary line drawn perpendicularly (at 90°) to a point on a surface where the light beam strikes

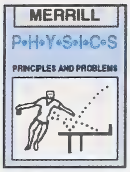
4. What is the angle of incidence in degrees?

5. What is the angle of reflection in degrees?

6. What is the law of reflection?

Conclusion

7. How does a beam of light behave when it reflects from a shiny surface?



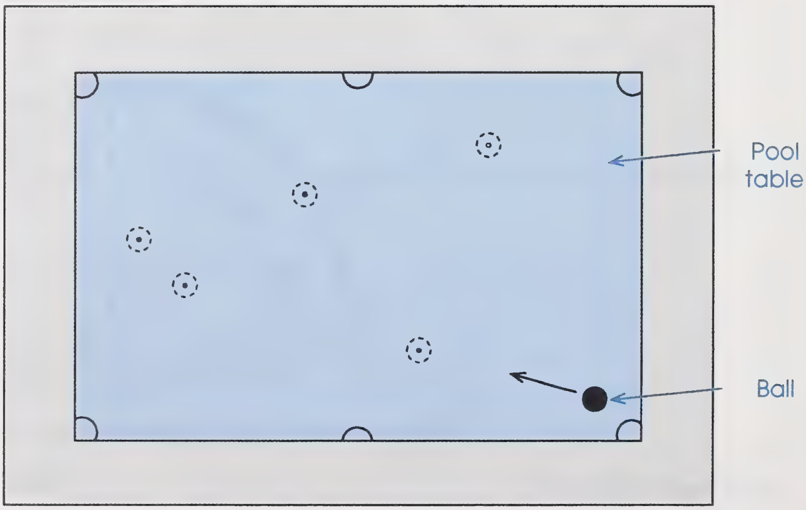
Reflection does not always occur on mirrors. Read page 348 in your textbook and study Figure 17-2 on page 349 to answer the following questions.

8. What is regular reflection?

9. What is diffuse reflection?

10. Do both types of reflection follow the law of reflection?

The following diagram shows the time-elapsed motion of a ball reflecting off the side of a pool table. This diagram illustrates that particles can also be reflected. Use the diagram to answer the following questions.



11. Draw and label these things on the diagram of the pool table.

- a line depicting the motion of the incident ball striking the side
- a line depicting the motion of the reflected ball off the side
- a line depicting the normal
- angle of incidence
- angle of reflection

12. Use a protractor to measure the angles of incidence and reflection for the ball. Record your answers on the diagram of the pool table.

13. Do particles follow the law of reflection?

14. Do waves follow the law of reflection? Refer to page 229 in your textbook to help you answer.

Check your answers by turning to the Appendix, Section 1: Activity 4.

You can see that light does follow the law of reflection, but reflection does not prove that light travels as a wave or a particle. To determine whether the particle or wave model is best, further observations of light will have to be made and compared to each model.

Follow-up Activities

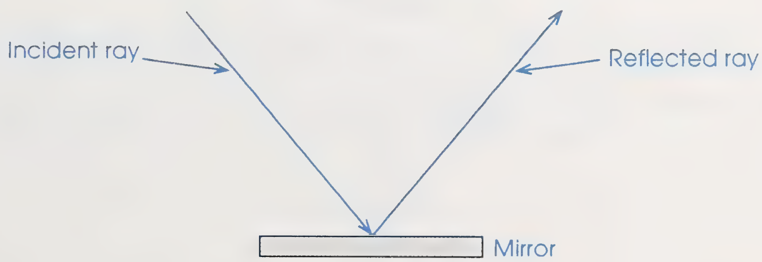
If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. There were two proposals for light energy propagation in the seventeenth century A.D. Name the person who proposed each theory and state each theory.

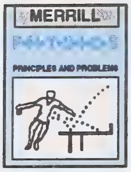
2. Draw a diagram to illustrate one situation that proves that light travels in a straight line.

3. The following diagram shows a beam of light reflecting off a mirror. Use a protractor to determine the value for the angle of reflection.



4. You have studied two properties of light – reflection and propagation. Which theory of light do these properties best support?

Check your answers by turning to the Appedix, Section 1: Extra Help.



5. Turn to page 332 of your textbook and do Practice Problems 1, 4, and 5.

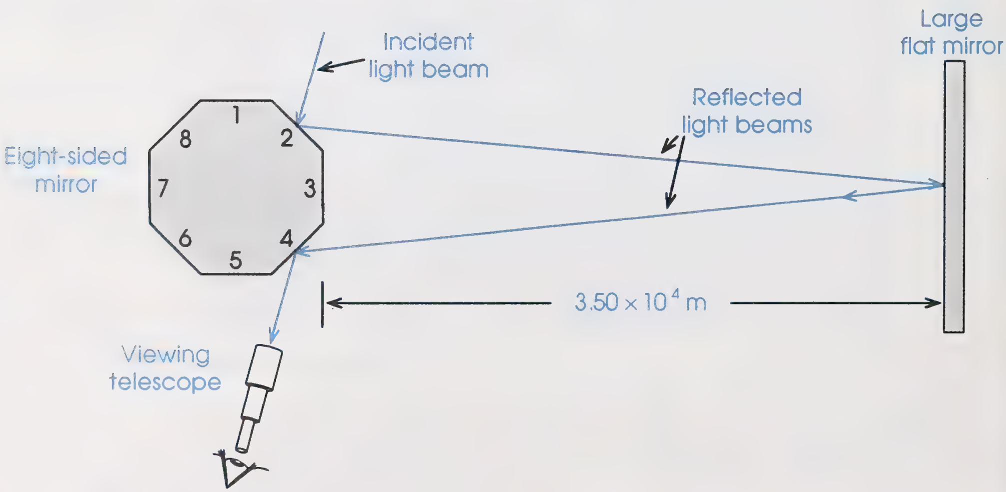
Check your answers by turning to page 677 in your textbook.

Enrichment

Do **one** of the following questions.

1. Michelson's attempt to calculate the speed of light was a classic experiment. His attempt displayed both properties of light. A simplified version of his attempt is described.

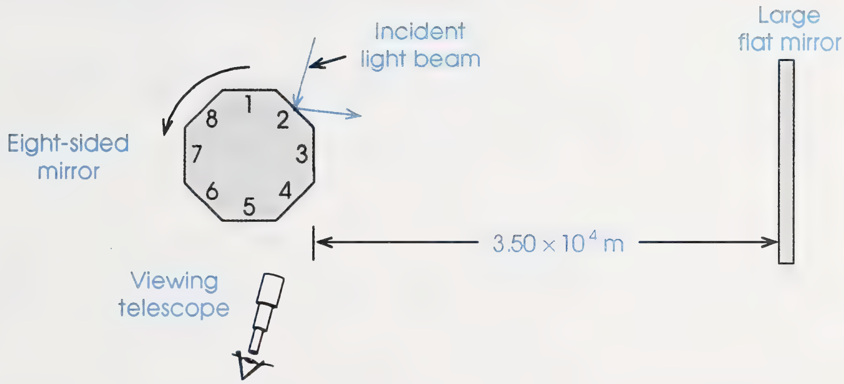
   Michelson used a large eight-sided mirror and a flat mirror that was positioned 3.50×10^4 m away. He stated that if a narrow beam of light strikes face 2 of the rotating mirror at the proper angle, it should reflect to the large flat mirror and reflect back to the eight-sided mirror, striking face 4 of the rotating mirror at the proper angle so that it will reflect into a viewing telescope.



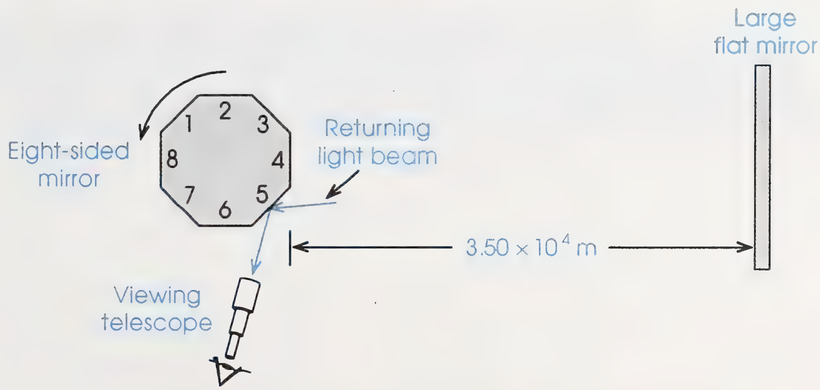
a. Given the previous description, how far will the incident light beam travel between face 2 and face 4?

b. Even if the eight-sided mirror was as large as 1 m in diameter, why doesn't the distance between face 2 and face 4 matter when answering part a?

Now imagine that the mirror is rotating.



In the time that the light takes to leave the rotating mirror and travel to the large flat mirror and back, the mirror has rotated so that the returning light beam strikes face 5. This is one-eighth of a rotation.

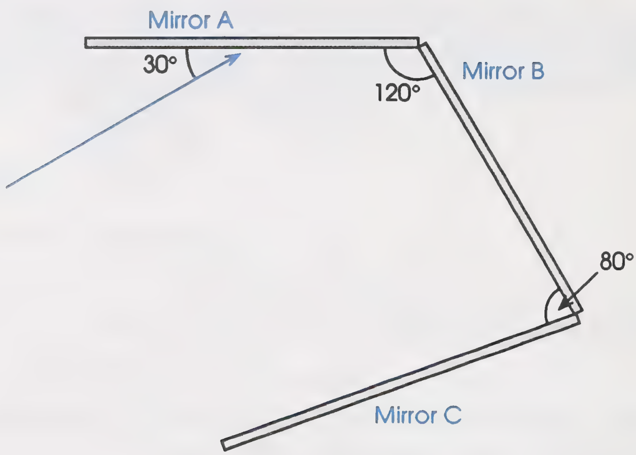


For the returning light beam to strike face 5 as shown in the previous diagram, the rotating mirror must make 536 rotations per second. It is possible to calculate the time for one-eighth of a rotation. It is the same as the time for the light to travel to the flat mirror and back.

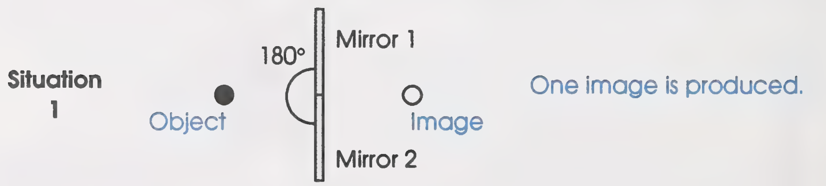
c. How long does it take for the mirror to make one-eighth of a rotation (in seconds)?

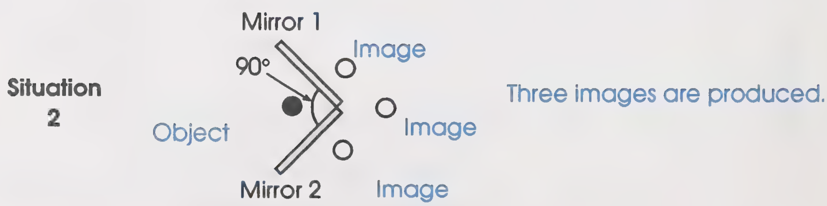
d. Use the distance from part a and the time from part c to calculate the value for the speed of light that Michelson would have obtained.

2. A ray of light strikes an arrangement of reflecting mirrors at the angle shown. Find the angle of reflection of the beam of light off mirror C. Show all calculations on the diagram.



3. Study the following situations involving images of reflections produced by flat mirrors and then answer the following questions.





a. How many images would be produced by two flat mirrors positioned at 45° to each other?

b. Devise an equation to determine the number of images (n) formed when two flat mirrors are placed at any angle (θ) to each other.

Check your answers by turning to the Appedix, Section 1: Enrichment.

Conclusion

At the beginning of this section you were asked to speculate how light could travel from the sun to the earth. You've seen that there are two competing descriptions for the movement of light through space – the wave model and the particle model.

In order to decide which model was best, you observed the straight line propagation and reflection of light. Since both models explain these things equally well, you have no choice but to observe other properties of light to determine which model is best.

In the next section you will observe the behavior of light as it undergoes refraction, polarization, and displays colours. Observations of these properties should help you to identify which model is best.

Assignment Booklet

ASSIGNMENT

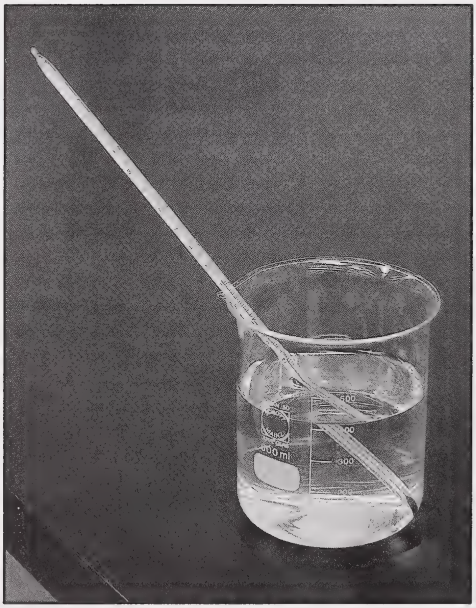
Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Refraction, Colour, and Polarization

As Isaac Newton was formulating the theory of universal gravitation, he attempted to make a telescope to observe the motions of the planets in the universe. However, when he looked through his telescope, he noticed a mysterious ring of colours surrounding all images. Where did these marvelous colours come from? Were the colours produced by magic? Were they produced by the glass in the lenses of the telescope? Were they present in the light passing through the telescope? Newton was so curious that he began a thirty-year study of light and colour, culminating in the publication of his book *Optiks* in 1704.

In this section you will complete an investigation that explores the refraction of light. You will then analyse the data to determine the mathematical description for refraction. You will also learn how early experiments with the refraction of light led to an explanation for the colours of light and the colours of objects. Finally, you will investigate the ability of light to be polarized and you will see how this property can be applied to everyday technology.



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Activity 1: Refraction of Light

Before proceeding with further investigations of the properties of light, it would be a good idea for you to review the concepts already discussed and preview the topics to be investigated in this section.

PATHWAYS

If you have access to the video entitled *The Behaviour of Light*, do Part A. If you do not have access to the video, do Part B.

Part A

The video provides an interesting overview of many of the topics in this module. Prior to watching the program, familiarize yourself with the following questions. As you watch the video, it may be necessary to stop the video so that you can record your answers.

1. Throughout history many people have contributed to the current base of knowledge about light. For each part of this question, describe what each of the following people or groups of people contributed to the knowledge about light.

   a. The ancient Greeks began many ideas about the nature of light. Identify three ideas that were contributed.

   b. Until Galileo worked with light, it was thought that light travelled instantaneously from point to point. What new idea did Galileo add about the speed of light?

   c. The Dutch physicist, Christian Huygens, suggested something quite different from the Greeks' ideas about the nature of light. What was Huygens' new idea?

   d. The Scottish mathematician, James Clerk-Maxwell, took the model of light in radically new directions with the suggestion that light relates to electricity and magnetism. How did Maxwell think that light energy was carried?

   e. Many people are surprised to know that Albert Einstein received his Nobel prize for his ideas about light, not for his work on relativity. What did Einstein think light was?

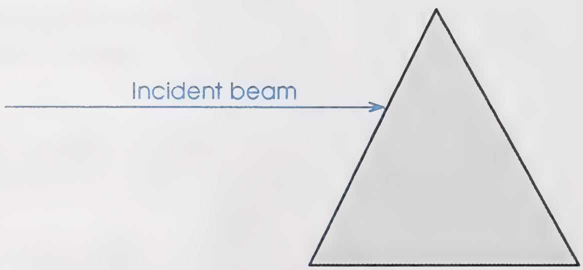
2. The fact that light can travel from a star that is billions of kilometres away and stimulate electrons in your retina demonstrates an important property of light and all other electromagnetic waves. What is this property?

3. What does a photomultiplier detect and record?

4. Construct a chart with the same headings as the one shown. Then complete the chart by recording the appropriate key words or phrases. You may need to adjust the size of your chart according to the length of your answers.

Comparing Light from a Flashlight and a Laser		
Characteristics	**White Light from a Flashlight**	**Laser Light**
Coherent or Incoherent	incoherent light	coherent light
Description of Photons Emitted		
Description of Beam Produced		

5. The video shows a beam of laser light striking a prism. Label the following diagram of a prism to show how the laser light beam leaves the prism.



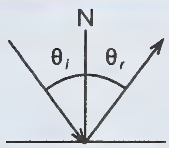
6. In Module 5 you learned about many of the behaviours of waves. Other than reflection or refraction, what other properties does light exhibit?

End of Part A

Part B

This activity is designed to allow you to apply the main ideas of Module 5 to this module. You will use pages 328 to 402 of your textbook to look for photographs that demonstrate the wave nature of light.

7. You will need to construct a chart with the same headings as the sample shown. Complete the first two columns of this chart. Refer to Module 5 or your textbook if necessary. You should adjust the size of your chart according to the length of your answers.

Evidence of Light Acting as a Wave in Photographs			
Wave Property	**Description of the Property**	**Labelled Diagram of the Property**	**Textbook Pages**
Reflection	Waves reflect from a boundary such that $\theta_i = \theta_r$.		348, 349, 350, 370, 375, 377
Refraction			
Diffraction			
Interference			

8. Complete the last column of the chart by scanning pages 328 to 402 of your textbook. Look for photographs that demonstrate each of the wave properties. You may find it helpful to quickly flip through all the pages to look for the photographs for one property and then go back and quickly flip through again for the next property. Be sure to identify photographs, not line drawings.

Check your answers by turning to the Appendix, Section 2: Activity 1.

End of Part B

In the previous section you learned that light does propagate in a straight line at a speed of 3.00×10^{8} m/s in a vacuum and that it will obey the law of reflection.

Investigation: Light Travels from Air into Glass

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Purpose

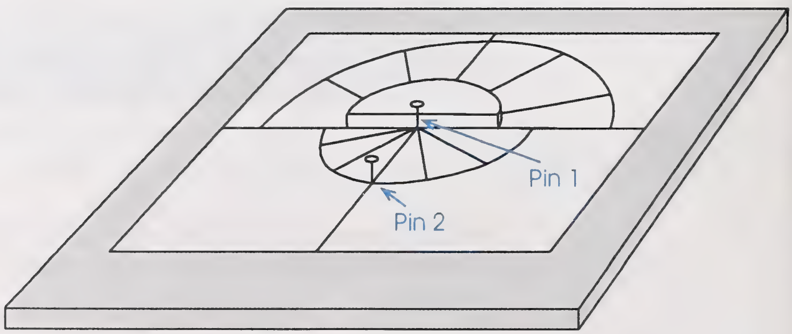
In this investigation you will determine how light behaves when it travels from air into glass.

Materials

- semicircular glass dish (D-dish) that is 8.60 cm in diameter
- soft smooth board measuring about 0.5 m by 0.5 m (A ceiling tile or piece of corrugated cardboard would be ideal.)
- three small stick pins
- ruler
- tape

Procedure

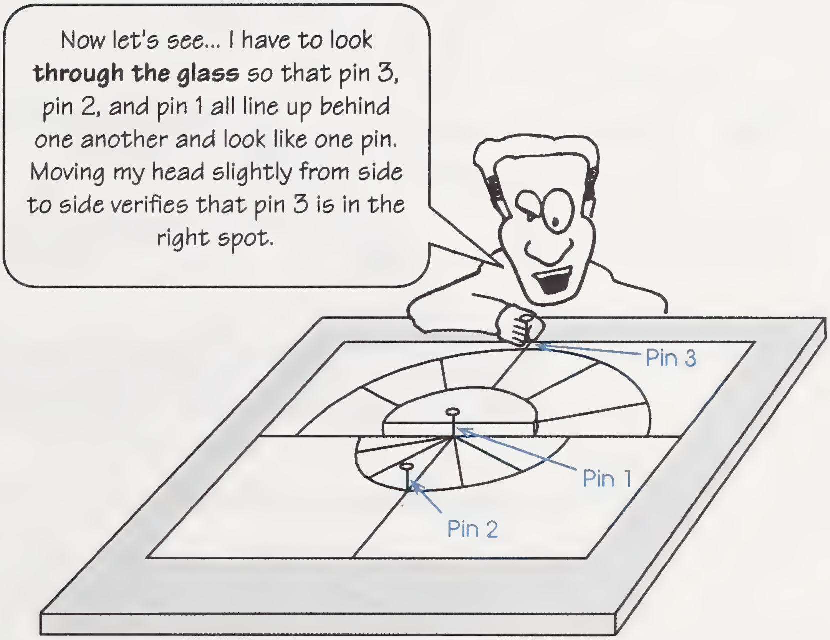
- A page of polar graph paper shows the set up of the apparatus for this investigation. This page is found in the Appendix. Tear out the page and tape it to the soft board. Be sure to tear out the correct page. Check the investigation title printed at the top of the page.
- Place the D-dish so that its flat side runs flush along the flat side of the shaded area on the pull-out page. Make sure that the D-dish is centred on the shaded area.
- Place pin 1 on point P_1, as shown in the following diagram.



- Place pin 2 at the 0° mark, as shown in the preceding diagram.

- Look through the rounded edge of the D-dish and place pin 3 on the paper so that all three pins are exactly in line.

- When your eye is in the proper position, the light travels from pin 2 to pin 1, through the D-dish, and then to pin 3 and your eye. A common error made by students is that they look above the D-dish so that the light travels in the air the whole time. You'll know that you're doing it right if the lower parts of pin 1 and pin 2 look blurry because you are viewing them through the block of glass.



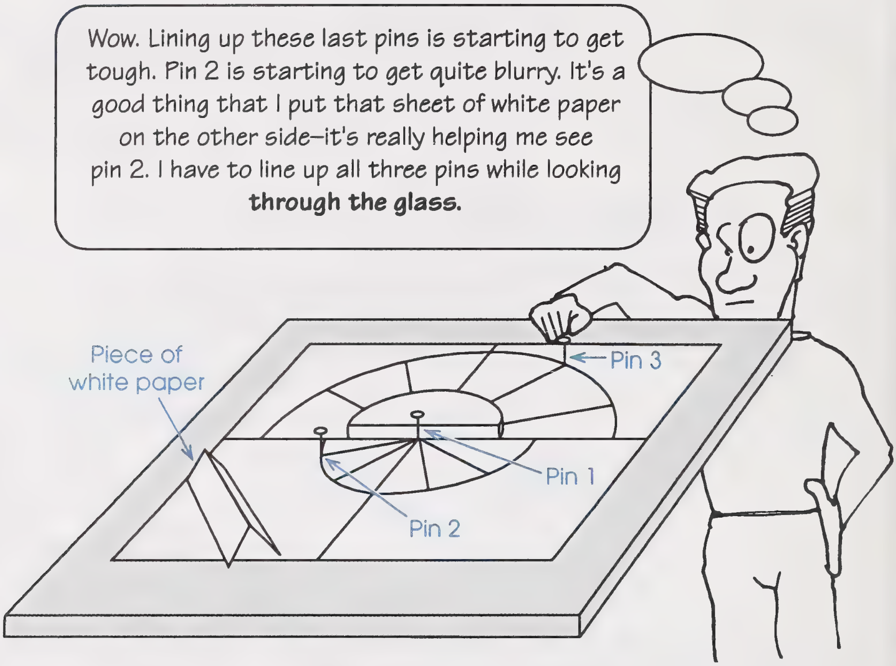
- It is vital that the D-dish does not move during this investigation. Check its position after every measurement.

9. Record the angle of incidence (θ_{air}), which is the angle between pin 2 and the normal, and the angle of refraction (θ_{glass}), which is the angle between pin 3 and the normal, in Table 1 on the next page.

   - Repeat the procedure by placing pin 2 at the 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, and 90° positions and use pin 3 to locate the position of each image.

   - Remember to check the position of the D-dish after every measurement.

- One way to tell if you are doing this properly is to compare the angles between pin 3 and the normal with some of the values provided on the chart. The values that you obtain should be reasonably close to the values provided.



Observations and Analysis

10. Record θ_{air} and θ_{glass} in the following data table. Since this procedure takes practice, some of the values have been supplied for you so that you can check your technique as you go.

Table 1

θ_{air}	θ_{glass}	θ_{air}	θ_{glass}
0.0°	0.0°	**50.0°**	30.7°
10.0°	6.7°	**60.0°**	
20.0°		**70.0°**	38.8°
30.0°	19.5°	**80.0°**	
40.0°		**90.0°**	41.8°

You have learned that an object can only be seen if light travels in a straight line from the object to your eye. When you were sighting your pins, light had to travel in a straight line through air (medium 1), along a line joining pins 1 and 2, and through the D-dish (medium 2) to pin 3.

Study your results in Table 1 and answer the following questions.

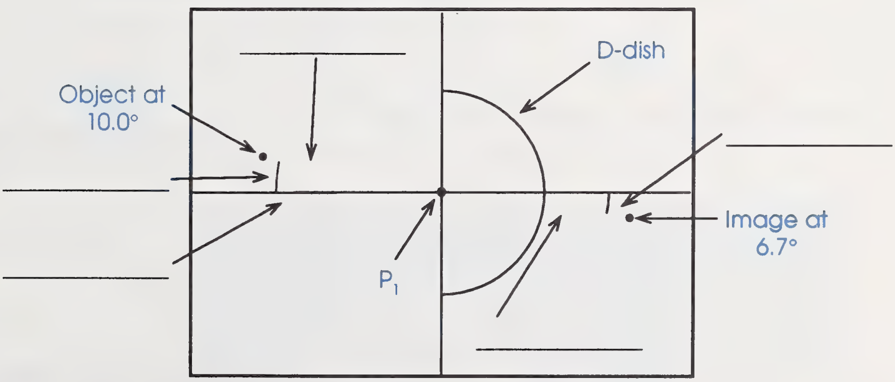
11. When did light appear to travel in a straight line between pins 2 and 3?

12. What did the ray of light appear to do in all other positions?

13. Did the light appear to bend towards the normal or away from the normal as it passed through the D-dish?

14. Draw or label each of these things on the following diagram.

    - Draw a ray of light from the object at 10.0° to point P_1. Label this ray as the incident ray.
    - Label the normal.
    - Label the incident angle as θ_{air}.
    - Draw a ray of light from the image at 6.7° to point P_1. Label this ray as the refracted ray.
    - Label the refracted angle as θ_{glass}.



15. Did the light bend at the flat side or the curved side of the D-dish?

16. Explain your answer to the previous question.

Conclusion

17. Does light bend towards or away from the normal when it travels from a less dense medium to a more dense medium?

Investigation: Light Travels from Glass into Air

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Purpose

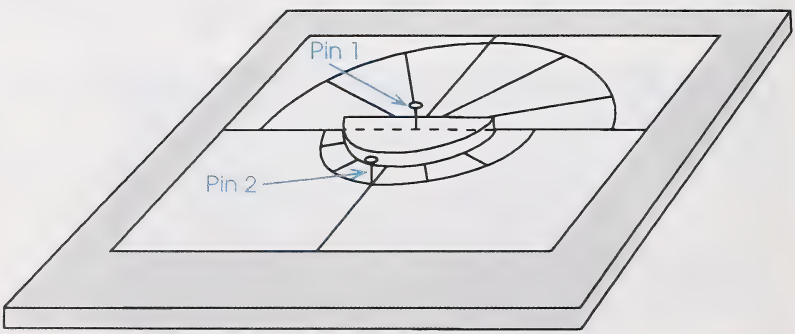
In this investigation you will determine how light behaves when it passes from glass into air.

Materials

The materials for this investigation are the same as for the last investigation.

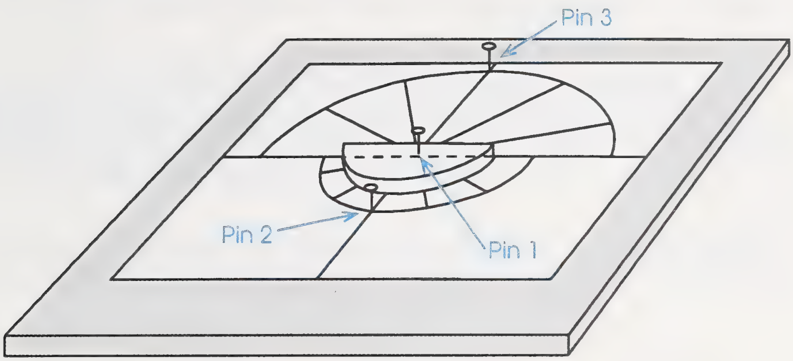
Procedure

- A page of polar graph paper shows the setup of the apparatus for this investigation. This page is found in the Appendix. Tear out this page and tape it to the soft board. Be sure to tear out the correct page. Check the investigation title printed at the top of the page.
- Place the D-dish flush against the centre line in the shaded area. Make sure that the D-dish is centred along the line.
- Place pin 1 on point P_1, as shown in the following diagram.



- Place pin 2 at the 0° mark, as shown in the diagram.

- Look through the flat side of the D-dish and place pin 3 on the paper so that all three pins are exactly in line.



- It is vital that the D-dish does not move during the investigation. Check its position periodically.

18. Record the angle of incidence (θ_{glass}), the angle between pin 2 and the normal, and the angle of refraction (θ_{air}), the angle between pin 3 and the normal, in Table 2.

- Repeat the procedure, placing pin 2 at the 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, and 90° positions and use pin 3 to locate the image positions.

You probably noticed that when pin 2 is placed at angles of 50° or greater, there is no angle of refraction. It seems like the angles in the air got too large.

Observations and Analysis

19. Record θ_{glass} and θ_{air} in the following data table. Some of the values have been supplied for you so that you can check your technique as you go.

Table 2

θ_{glass}	θ_{air}	θ_{glass}	θ_{air}
0.0°	0.0°	**50.0°**	no image
10.0°	15.1°	**60.0°**	no image
20.0°		**70.0°**	
30.0°	48.5°	**80.0°**	no image
40.0°		**90.0°**	no image

Study your results in Table 2 and answer the following questions.

20. When did the light appear to travel in a straight line from pin 2 to pin 3?

21. What did the light appear to do in all other positions?

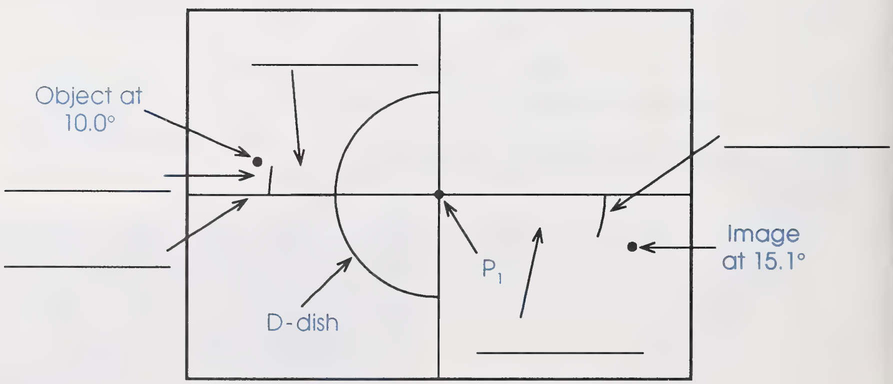
22. At what angle in the glass did the image seem to disappear?

23. Where is the image appearing when it can't be seen from the flat side?

24. Did the light appear to bend towards the normal or away from the normal as it passed from the glass into air?

25. Draw or label each of these things on the following diagram.

    - Draw a ray from the object at 10.0° to point P_1. Label this ray as the incident ray.
    - Label the normal.
    - Label the incident angle as θ_{glass}.
    - Draw a ray from point P_1 to the image at 15.1°. Label this ray as the refracted ray.
    - Label the refracted angle as θ_{air}.



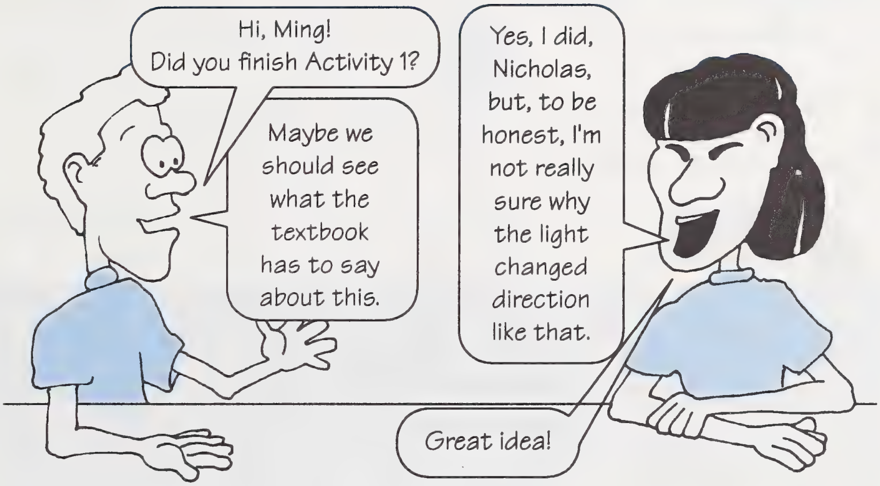
26. Did the light bend at the flat side or the curved side of the D-dish?

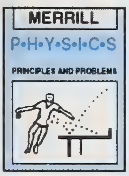
Conclusion

27. When light passes from glass into air, will it bend towards or away from the normal?

Check your answers by turning to the Appedix, Section 2: Activity 1.

Activity 2: Snell's Law





Read pages 348 to 350 of your textbook to learn why light changed direction in Activity 1. Answer the following questions when you finish reading.

1. What name is given to the bending of light due to a speed change at the boundary between two media?

2. Look at Figure 17-3 on page 349 of the textbook. What is the cause of this deflection towards the normal?

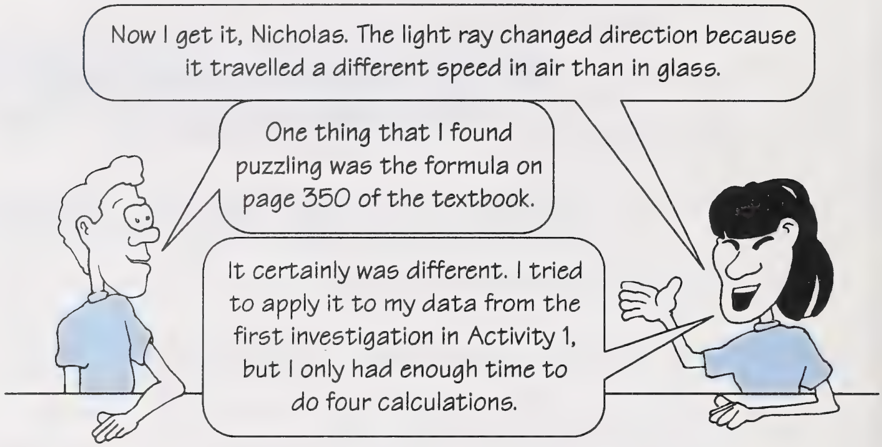
3. Look at Figure 17-4 on page 350 of the textbook. What is the cause of this deflection away from the normal?

4. What do you think is the cause of the refraction of light as it crosses the air-glass boundary in the following situations? Use the answers to the previous two questions as an analogy.

   a. from air to glass

   b. from glass to air

5. Based on your answer to question 4 and your work in Module 5, does light travel at the same speed in all media? If not, what is the relationship between the speed of light and the density of the medium?



Science Skills

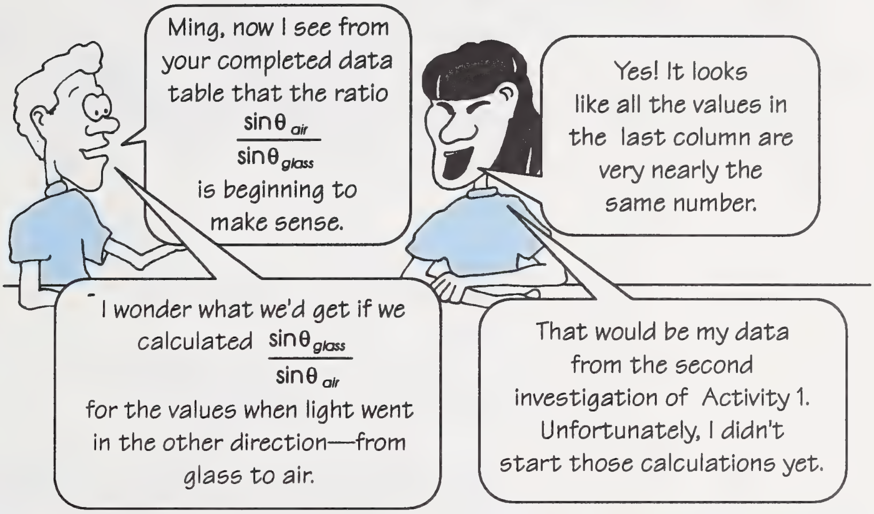
- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

6. Ming's partially completed data table follows. Complete the rest of the table.

Data for Light Travelling from Air into Glass

Position	θ_{air}	θ_{glass}	$\sin\theta_{air}$	$\sin\theta_{glass}$	$\frac{\sin\theta_{air}}{\sin\theta_{glass}}$
1	0.0°	0.0°	0.0000	0.0000	undefined
2	10.0°	6.7°	0.1736	0.1167	1.49
3	20.0°	13.0°	0.3420	0.2250	1.50
4	30.0°	19.5°	0.5000	0.3338	1.50
5	40.0°	25.5°			
6	50.0°	30.5°			
7	60.0°	35.5°			
8	70.0°	39.0°			
9	80.0°	41.0°			
10	90.0°	42.0°			

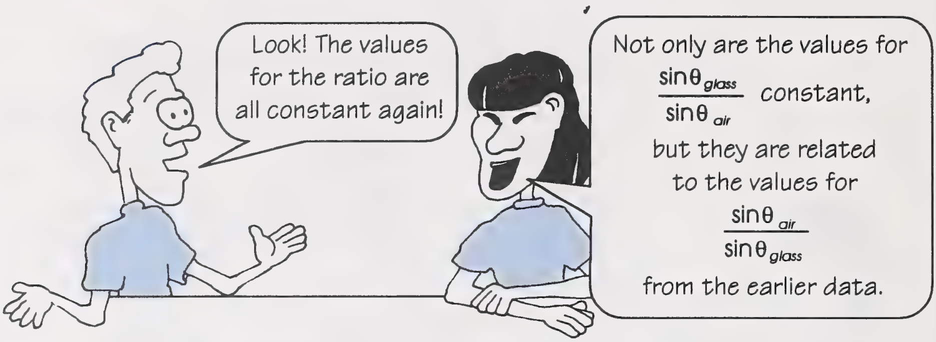
7. What is the average value of the ratios in the last column of the data table? Only use positions 2 to 10 in your calculation since the value for position 1 is undefined.



8. Complete the calculations for Ming's data.

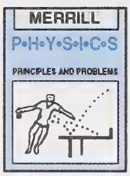
Data for Light Travelling from Glass into Air					
Position	θ_{glass}	θ_{air}	$\sin\theta_{glass}$	$\sin\theta_{air}$	$\frac{\sin\theta_{glass}}{\sin\theta_{air}}$
1	0.0°	0.0°	0.0000	0.0000	undefined
2	10.0°	15.0°			
3	20.0°	30.0°			
4	30.0°	48.5°			
5	40.0°	75.0°			
6	50.0°	no image			
7	60.0°	no image			
8	70.0°	no image			
9	80.0°	no image			
10	90.0°	no image			

9. What is the average value of the ratios in the last column? Use only positions 2 to 5 since position 1 is undefined and no images were produced for positions 6 through 10.



10. How does your average value from question 7 compare to the average value from question 9?

11. The averaging technique that you used in the previous questions is called a formula-data substitution technique. By using this technique, you were able to obtain an average value for the ratios of the sines of the angles. Can you suggest another averaging technique that would have obtained the same value?



The equation that was used to get the constant value for Ming's data is described on the bottom of page 350 in your textbook. Reread this section and answer question 12.

12. Use the following equation to answer the following questions.

$$n_{glass} = \frac{\sin\theta_{air}}{\sin\theta_{glass}}$$

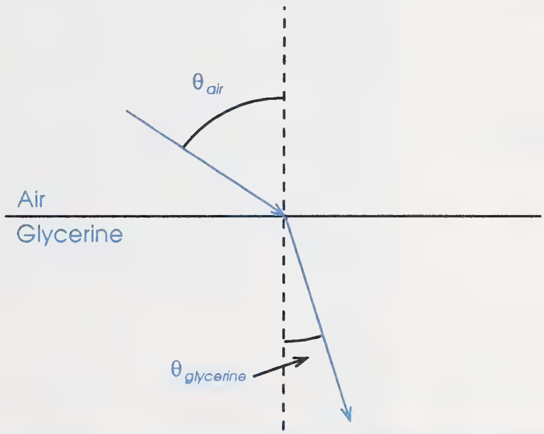
a. What name is given to the constant n?

b. What name is given to the entire equation?

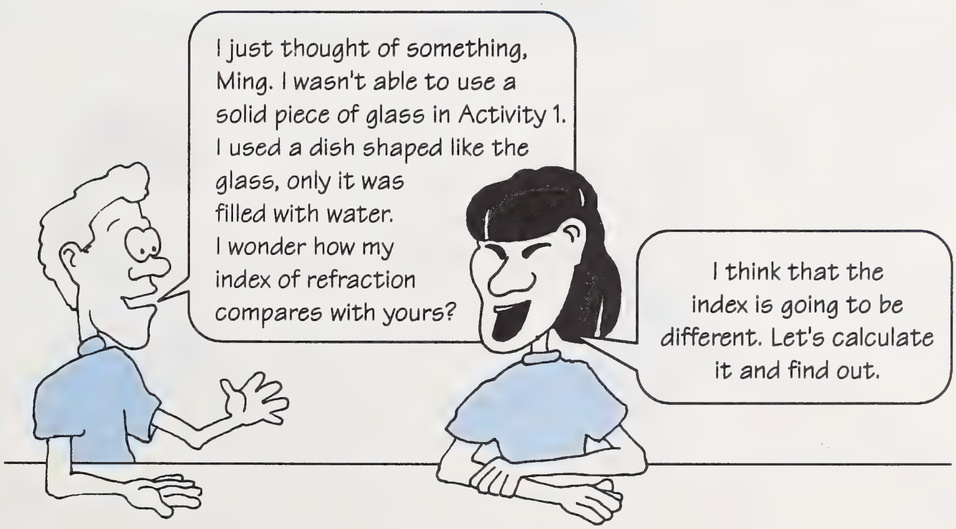
It is important to realize that this version of Snell's law is only valid for situations in which light travels from a vacuum into some material. Since the results will be very nearly the same for light travelling from air into the material, it is also correct to use it in that circumstance.

The textbook uses the angle of incidence (θ_i) and the angle of refraction (θ_r) in the equation for Snell's law. The version presented in this module booklet identifies the index and both of the angles in terms of the medium that these values represent. This tends to be a more successful approach to problem solving, so you are expected to use the version presented in the module booklet.

13. How should Snell's law be written to describe the following situation?



Check your answers by turning to the Appedix, Section 2: Activity 2.



14. The following data was collected by Nicholas when he let light travel from air into the water in his D-dish. Calculate the index of refraction for each set of points and determine the average of Nicholas' values.

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Data for Light Travelling from Air into Water

Position	θ_{air}	θ_{water}	$\sin \theta_{air}$	$\sin \theta_{water}$	n_{water}
1	0.0°	0.0°	0.0000	0.0000	undefined
2	10.0°	7.2°			
3	20.0°	15.5°			
4	30.0°	22.0°			
5	40.0°	29.0°			

Average =

15. Summarize the results of both Ming's and Nicholas' data on the following chart.

	Light Travelling from Air into Water	Light Travelling from Air into Glass
Index of Refraction		

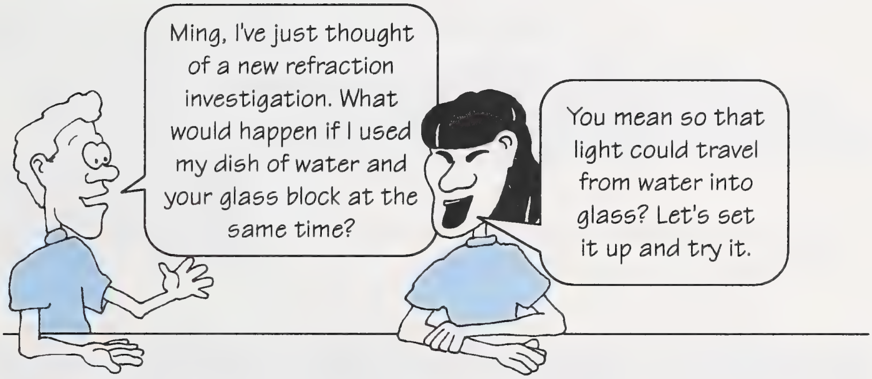
16. Examine Table 17-1 on the top of page 353 in your textbook to determine the index of refraction for light travelling from a vacuum into each of the following substances.

    a. water b. crown glass c. diamond

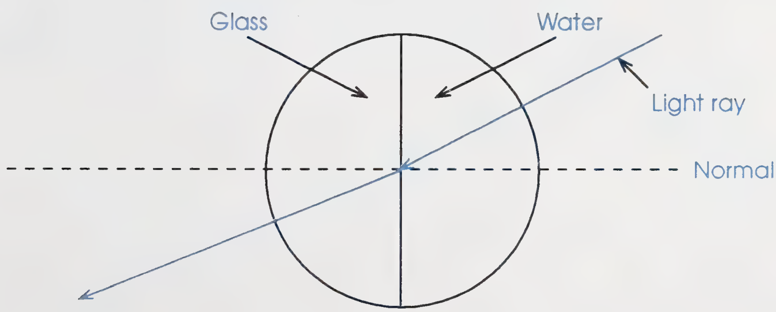
17. Diamond has the highest index of refraction in Table 17-1. Use this fact and what you know about the cause of refraction to answer these questions.

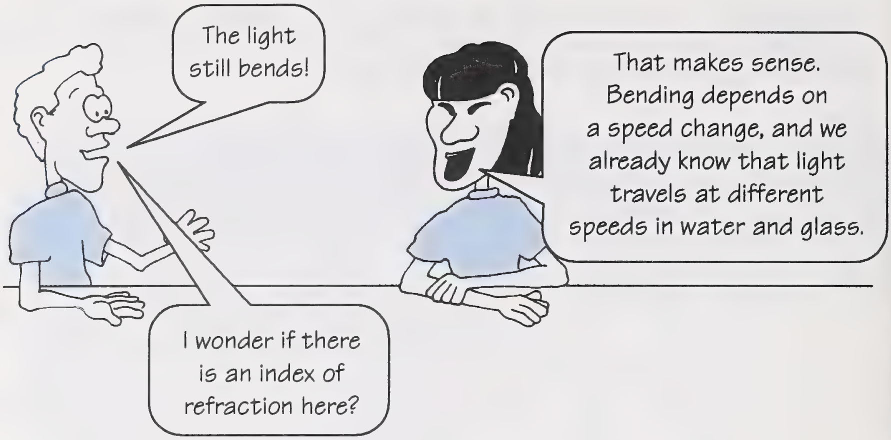
    a. How would the angle of refraction compare to the angle of incidence for light travelling from air into diamond?

    b. How would the speed of light in diamond compare to the speed of light in air?



When Ming and Nicholas got their equipment set up, it looked like this.





In this case, the ratio of $\dfrac{\sin \theta_{water}}{\sin \theta_{glass}}$ equals the ratio of the index for glass divided by the index for water.

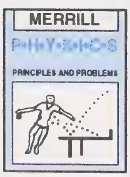
$$\boxed{\frac{n_{glass}}{n_{water}} = \frac{\sin \theta_{water}}{\sin \theta_{glass}}}$$

A more general equation for light travelling from any medium into another medium replaces the names of the specific media with numbers.

$$\boxed{\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}}$$

18. What do the following symbols represent?

    a. n_1 b. θ_1 c. n_2 d. θ_2



19. Another accomplishment of Snell led to an important technological advancement. What was that accomplishment? Read F.Y.I. on page 350 in your textbook to help you answer.

Snell's general equation may be used to calculate the index of a medium or the angle in a medium.

For questions 20 and 21, use the problem-solving strategy outlined on page 353 of the textbook.

20. A ray of light travelling in air (n=1.00) strikes a quartz plate (n=1.54) at an angle of incidence of 45.0°. What is the angle of refraction in the quartz?

21. A ray of light travelling in air (n=1.00) strikes a glass plate at an angle of 30.0°. The angle of refraction in glass is 19.2°. Calculate the index of refraction of glass.

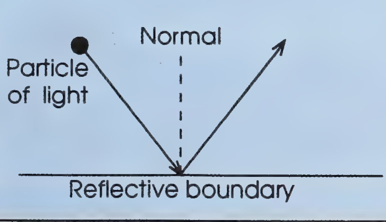
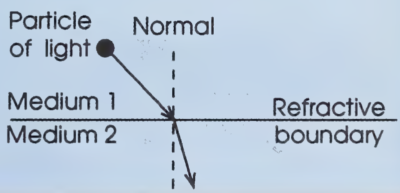
Check your answers by turning to the Appedix, Section 2: Activity 2.

MERRILL
P•H•Y•S•I•C•S
PRINCIPLES AND PROBLEMS

22. Do Practice Problems 1 to 4 on page 354 of your textbook.

Check your answers by turning to pages 677 and 678 of your textbook.

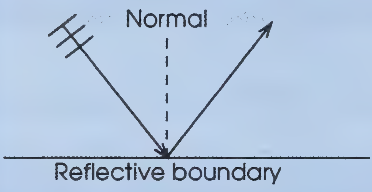
After Snell had derived his general equation, Newton tried to explain the reflection and refraction of light using his particle theory. His explanation is summarized in the following chart.

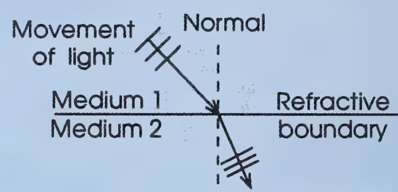
Newton's Particle Model Explanations	
Reflection of Light	**Refraction of Light**
As a particle approaches a reflective boundary, it is repelled by the medium, causing the particle of light to bounce away so that the angle of incidence equals the angle of reflection.	As a particle of light approaches a refractive boundary, it is attracted into the medium. This attraction causes the particle to speed up when it enters the medium, causing it to bend towards the normal.
	

Huygens explained the reflection and refraction of light using the wave theory.

Huygens' Wave Model Explanations

Reflection of Light	Refraction of Light
As a light wave approaches a reflective boundary, it is reflected similar to a water wave so that the angle of incidence equals the angle of reflection.	As a light wave approaches a refractive boundary, it must slow down as it enters a more dense medium and bends towards the normal.





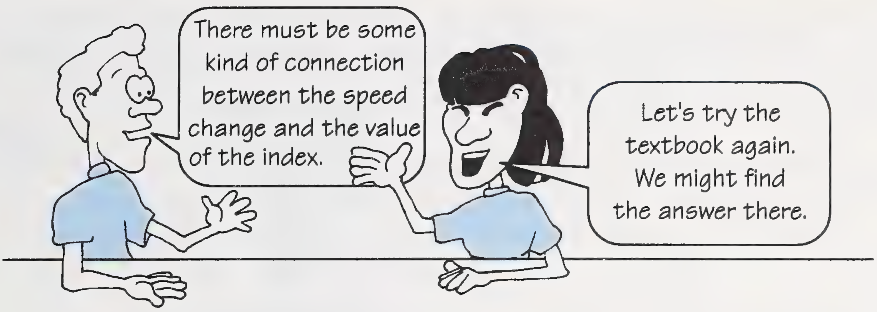
23. Are both theories for reflection similar?

24. Can you use reflection to prove either the wave or particle theory of light?

25. What is the main difference between the theories for refraction?

26. Can you use refraction to prove either the wave theory or the particle theory of light?

27. In the 1800s Fizeau and Foucault conducted an experiment to compare the speed of light in water and the speed of light in air. They found that the speed of light was slower in water. Based on this conclusion, which theory of light is best, Newton's particle theory or Huygens' wave theory? Explain your answer.



Turn to pages 354 and 355 of your textbook and read through the derivation of the equation that relates the speed of light to the index of refraction.

A derivation of the equation that relates the speed of light to the index of refraction is outlined in the Enrichment activity of this section. For now, the equation is given as shown.

$$\boxed{\frac{v_1}{v_2} = \frac{n_2}{n_1}}$$

28. What do the following symbols represent?

    a. n_1 b. n_2 c. v_1 d. v_2

It is now possible to find the speed of light in any medium. Use the problem-solving strategy to solve the following problems.

29. A ray of light travels at 3.00×10^8 m/s in air (n=1.00). What is its speed as it enters glass (n=1.52)?

Check your answers by turning to the Appendix, Section 2: Activity 2.

30. Do Practice Problems 5 to 7 on page 355 of your textbook.

Check your answers by turning to page 678 of your textbook.

As light travels from one medium to another at an angle, the direction and speed may change. Since light is a wave, and for all waves $v = f\lambda$, does the frequency or the wavelength change?

Since frequency is determined by the source producing the wave, it must stay constant. Therefore, the wavelength must change. Look at the following derivation.

$$\boxed{\frac{v_1}{v_2} = \frac{n_2}{n_1}} \qquad \boxed{v = f\lambda}$$

Substitution

$$\boxed{\frac{\lambda_1 f_1}{\lambda_2 f_2} = \frac{n_2}{n_1}}$$

Frequency is constant. Therefore, f_1 equals f_2 and the frequencies cancel.

$$\boxed{\frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}}$$

31. What do the following symbols represent?

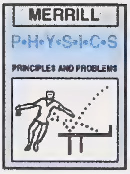
    a. n_1 b. λ_1 c. n_2 d. λ_2

32. If red light has a wavelength of 6.50×10^{-7} m in air (n=1.00), what is its wavelength in flint glass (n=1.61)?

33. Blue light has a wavelength of 4.60×10^{-7} m in air (n=1.00) and a wavelength of 1.90×10^{-7} m in substance x.

    a. Calculate the index of refraction for substance x.

    b. Use Table 17-1 on page 353 to identify substance x.



The previous two questions make an interesting point about describing the different colours of light. If wavelength is to be used to identify a colour of light, it is vital that the medium also be stated with the wavelength, since the wavelength will change if the medium has a different index of refraction.

As an example, imagine that you are tossing an orange Frisbee™ along a beach. When the Frisbee™ is in the air, the orange light that comes from it would have a wavelength of 6.1×10^{-7} m. If the Frisbee™ was accidentally tossed into the water and sank, the Frisbee™ would still look orange, even though the wavelength of the orange light would now be 4.6×10^{-7} m in the water.

The difficulty with the preceding explanation is that it still does not describe how orange light should be identified. In other words, what property of orange light should remain the same in both air and water? You should be able to answer this question using the flow chart on the previous page.

The frequency of the light is the property that remains constant in both air and water, with a value of 4.9×10^{14} Hz. It follows from this that the best way to describe orange light is in terms of its frequency, since this stays constant from one medium to the next.

In the next activity you will study colour from a much broader point of view. However, you will find it very helpful to keep in mind the points made here about wavelength and frequency.

In this activity you have seen Snell's law expressed in terms of sines of angles, speeds, and wavelengths, with each version having its own equation. These three equations can be combined into one statement of Snell's law.

$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2} \qquad \boxed{n_1 v_1 = n_2 v_2} \qquad \boxed{n_1 \lambda_1 = n_2 \lambda_2}$$

$$\downarrow \qquad\qquad \downarrow \qquad\qquad \downarrow$$

$$\boxed{\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}} \qquad \boxed{\frac{v_1}{v_2} = \frac{n_2}{n_1}} \qquad \boxed{\frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}}$$

$$\searrow \qquad\qquad \downarrow \qquad\qquad \swarrow$$

$$\boxed{\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}}$$

This general form of Snell's law allows you choose the relevant part of the equation and solve for the unknown variable.

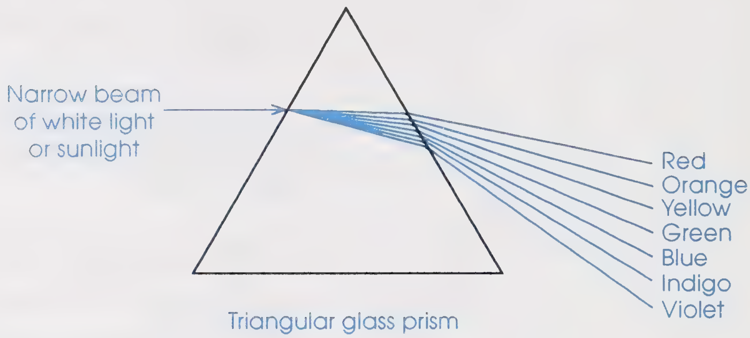
34. A ray of green light travels from air into plastic, making an angle of 15.0° in the air and an angle of 10.0° in the plastic. If the light has a wavelength of 5.5×10^{-7} m in air, what is its wavelength in plastic?

35. A ray of light passes from glass into air, making an angle of 46.0° in the air. If the speed of the light ray is 1.94×10^{8} m/s in glass, calculate the angle in the glass.

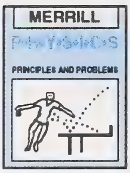
Check your answers by turning to the Appendix, Section 2: Activity 2.

Activity 3: Dispersion and Colour of Light

One of the first experiments that Newton performed was to pass a narrow beam of sunlight through a prism.



In Activity 1 you learned that the bending of light is called refraction. Newton's experiment with the prism explains why the beam of light bends, but why does it separate into bands of different colours?



Read pages 337 and 338 of your textbook and answer the following questions.

1. What did Newton call the ordered arrangement of colours?
2. What did Newton first assume was producing the arrangement of colours?
3. How did Newton try to test this assumption?
    a. Draw a diagram of the setup of the apparatus.
    b. What was Newton's hypothesis?
    c. What was the result of the experiment?
    d. What did Newton conclude was the source of the colours?

dispersion – the spreading of white light into the full spectrum of colours

The separation of white light into colours is called **dispersion**. Although Newton tried to explain this property by saying that each colour of light was a different shaped particle, the wave theory of light had a much better explanation. If light is a wave, each colour of light must have its own distinct wavelength.

Read page 330 in your textbook and answer the following questions.

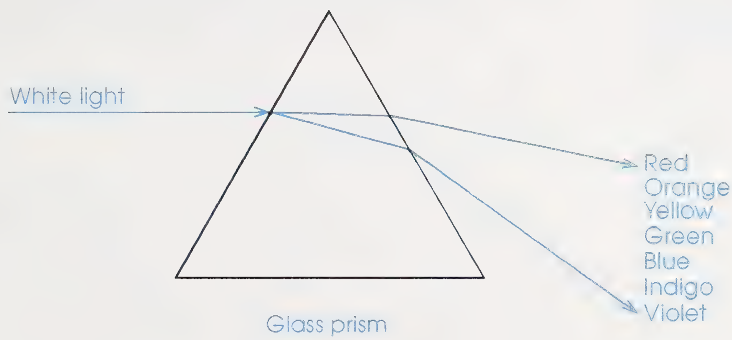
4. What is the wavelength range of all visible light?

5. Which colour has the shortest wavelength?

6. Which colour has the longest wavelength?

In a vacuum, all waves travel at the same speed ($c = 3.00 \times 10^{8}$ m/s), but in other media, waves of different wavelengths must travel at different speeds (The longer the wavelength, the greater the speed.).

Use the following diagram to answer questions 7 and 8.

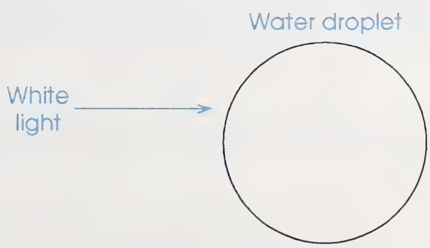


7. Which colour do you think slows down the least as it enters the glass?

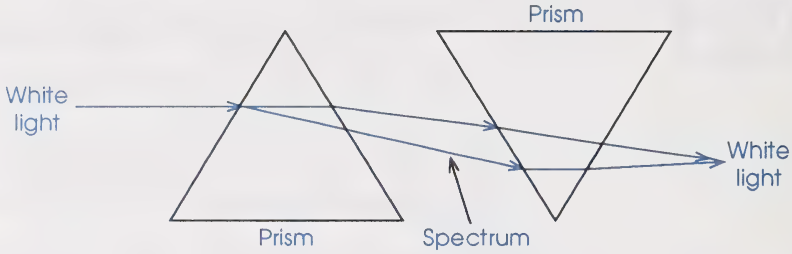
8. Which colour do you think slows down the most as it enters the glass?

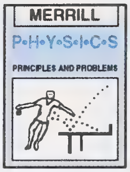
It is suggested that the spectrum produced by a prism is just an artificial rainbow. Read pages 360 and 361 in your textbook to learn how a rainbow is formed.

9. Use the following diagram to explain the formation of a rainbow.

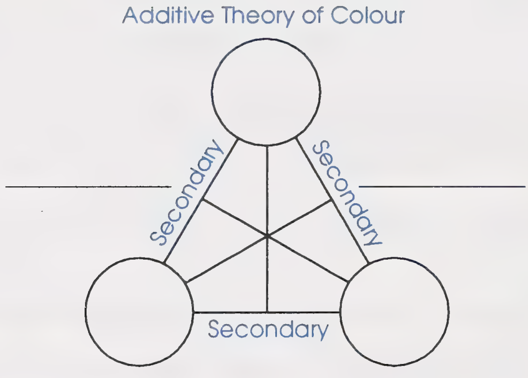


There are three methods to produce white light from coloured light. One method was to shine a spectrum of all colours through a reverse prism to produce white light.





A second method to produce white light from colours is to use the additive colour process. Refer to Figure 16-9 on page 338 of your textbook.



10. What are the three primary colours of light? Write their names in the circles on the previous diagram.

11. What colour do you get when you mix the three primary colours of light together?

12. When you add two primary colours together, you get secondary colours. Write the names of the secondary colours in the response blanks in the preceding diagram.

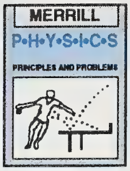
A third method of producing white light is to mix a complementary colour with its corresponding primary colour.

13. What is the complementary colour for blue light? Explain why white light is produced when these two lights are added together.

How can you explain the colours of objects? Newton said that the colour of an object depends on what colours it can absorb and what colours it can reflect.

14. a. When white light shines on a red book, what colour is reflected to your eyes?

    b. What colours are absorbed by the book?



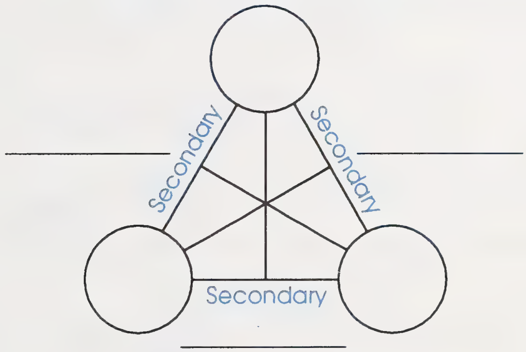
To learn more about the subtractive colour theory, read pages 338 and 339 in your textbook.

15. What is the name given to the absorption of colours?

16. The absorption of light in materials is achieved with dyes or pigments. What is the difference between a dye and a pigment?

17. Complete the colour chart for the subtractive process of colour. Write the names of the primary colours in the circles. Write the names of the secondary colours on the blanks.

Subtractive Theory of Colour



18. What is the relationship between the primary and secondary colours of the additive theory and the primary and secondary colours of the subtractive theory?

Check your answers by turning to the Appendix, Section 2: Activity 3.

Activity 4: Polarization of Light

polarizing material – a material that has long molecules that permit transverse waves vibrating in one plane to pass through

In Module 5 you learned that waves could propagate as either transverse or longitudinal waves. Is light a transverse or longitudinal wave? The answer to this question can be observed when light from a reflected surface is viewed through a **polarizing material**.

Investigation: Observing the Polarization of Light

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [ ] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Purpose

In this investigation you will observe light as it passes through one or two polarizing filters.

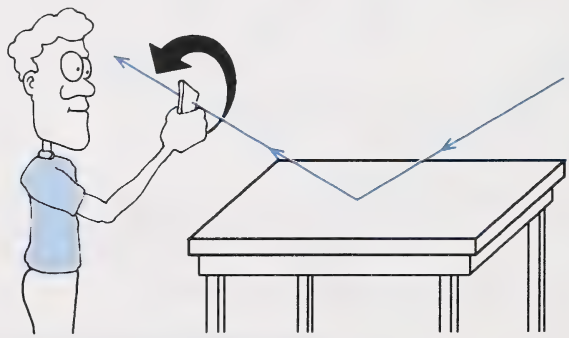
Materials

You will need the following materials for this investigation:

- two polarizing filters
- a light source
- a smooth horizontal surface

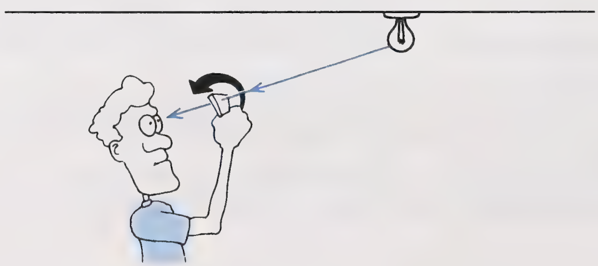
Procedure and Observations

- Observe the light that is reflected from a smooth horizontal surface through the polarizing filter. Rotate the filter as you look through it.



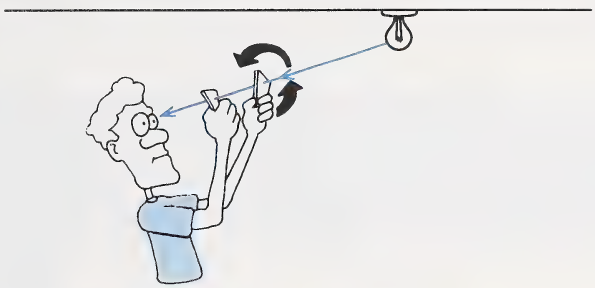
1. What do you observe as you rotate the filter?

- Observe the light from a light source through a polarizing filter. Rotate the filter as you look through it.



2. What do you observe as you rotate the polarizing filter?

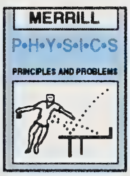
   - Observe the light from a light source through two polarizing filters. Hold one filter still and rotate the second filter.



3. What do you observe as you rotate one of the filters?

What you observed can be explained by studying a property of light called polarization.

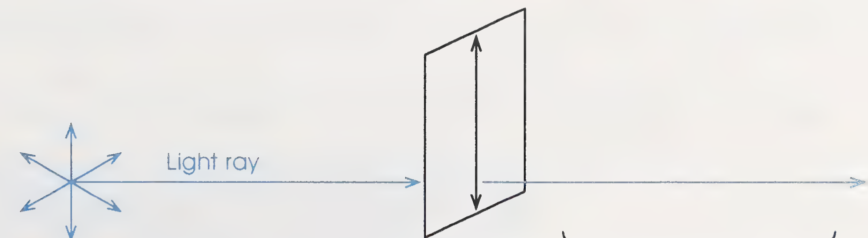
Analysis



Read pages 341 and 342 in your textbook and answer the following questions.

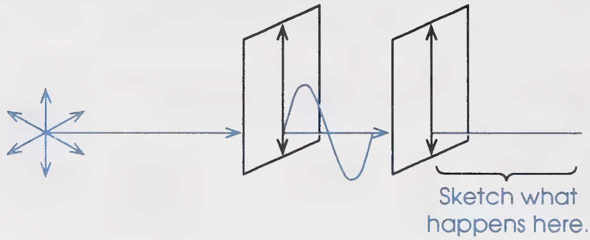
4. If light is a transverse wave, in which direction are normal light waves vibrating?

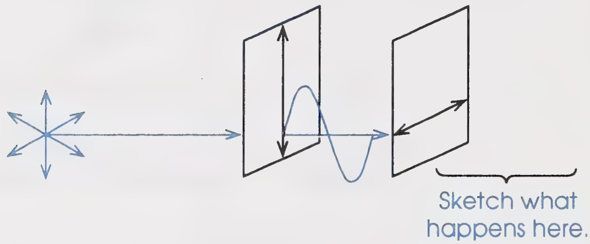
5. What does a polarizing material do to normal light waves? Complete the following sketch to illustrate your answer.



6. What is polarized light?

7. A second polarizer can be placed as shown. Explain what happens by completing the following sketches.





8. What is the second polarizer called?

Conclusions

9. Can particles or longitudinal waves be polarized?

10. What does the fact that light can be polarized prove?

Applications

11. Name two ways that light from the sun can be naturally polarized.

Check your answers by turning to the Appendix, Section 2: Activity 4.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. As light passes from one medium to another, it undergoes refraction and certain factors change. Construct a chart in your notebook that has the same headings as the sample shown. Then fill in your chart. You may need to adjust the size of your chart according to the length of your answers.

Factor of Light	How does this factor change as it passes from a low density to a high density medium?	How does this factor change as it passes from a high density to a low density medium?
Speed		
Direction		
Wavelength		
Frequency		

In this section you have learned many versions of Snell's law. These different forms can be summarized by one general equation.

$$\boxed{\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}}$$

Practise using this version of Snell's law by solving the problems that follow.

2. While passing from water into glass, a ray of yellow light had a wavelength of 4.0×10^{-7} m in the glass. The speed of light in the water was 2.26×10^{8} m/s and the speed in the glass was 1.97×10^{8} m/s.

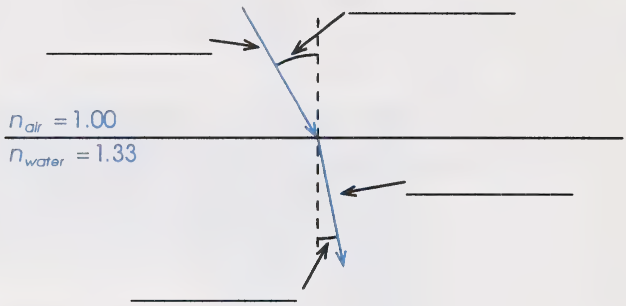
   a. Draw a sketch that includes all the variables.

   b. Use the general form of Snell's law to calculate the wavelength of the yellow light in the water.

   c. Check your answer by using the universal wave equation to solve for the wavelength of the yellow light in water.

3. A ray of light travelling at 3.00×10^{8} m/s in air (n=1.00) strikes a surface of water (n=1.33) at an angle of 30.0° to the normal.

   a. Complete the following diagram by adding the appropriate labels.



   b. Calculate the angle of refraction.

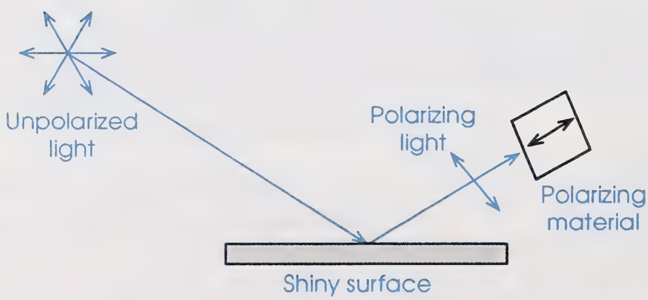
4. a. Construct and complete a chart in your notebook that has the same headings as the sample given.

Theory	What are its primary colours?	What are its secondary colours?
Additive		
Subtractive		

   b. Use the subtractive theory to explain why an object would appear black.

5. A student viewed a light beam that had reflected from a shiny surface through a polarizing filter, as shown in the following diagram.

   a. Complete the diagram.



b. What would be seen through the filter?

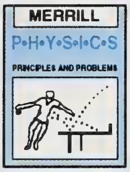
Check your answers by turning to the Appedix, Section 2: Extra Help.

Enrichment

Do **one** of the following questions.

1. If you have access to the booklet called Enrichment which accompanies your physics textbook, turn to page 30 of the booklet and do the activity for Chapter 17. The following changes have been made to this activity.

    - Only complete diagram A.
    - Use an angle of incidence of 40°.
    - Do not do the questions on page 31.



2. Study pages 354 and 355 of your textbook to help you derive the following equation. Refer to Figure 17-7 in your explanations.

$$\frac{v_1}{v_2} = \frac{n_2}{n_1}$$

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you studied the refraction, dispersion, colour, and polarization of light. These properties of light are largely in favour of the wave theory of light. By 1850 most scientists were convinced that light travels as a wave.

Assignment Booklet

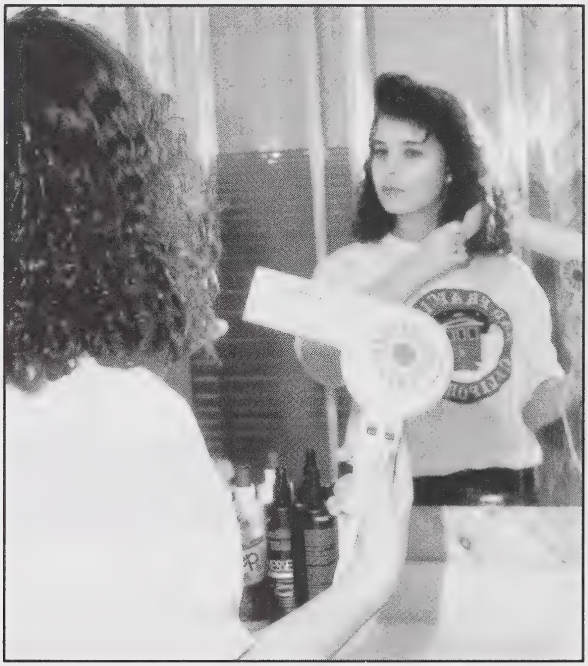
ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

Section

3 Images in Your Life

You have completed a thorough study of some of the properties of light and you have determined that light propagates as a transverse wave. Now you will apply these principles to the study of some devices that use these ideas.



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How is the image formed in the mirror?

In this section you will investigate the applications of the properties of light. You will first investigate the images formed by flat surfaces and then you will consider a special type of reflection called total internal reflection. In the last activity you will learn about some optical illusions caused by the refraction of light.

Activity 1: Images in Plane Mirrors

The property of reflection was probably the first property of light studied by man. Imagine the surprise that cavemen got the first time they saw strange creatures staring back at them when they leaned over a pool of water to get a drink! When they tried to touch the creatures, they magically disappeared into a series of ripples. Where did these images come from? How did they form? You will address these questions in the investigation that follows.

For the next investigation you will require some base material for supporting the mirror. You may use plasticine, putty, or something similar. If you don't have access to something like that, you may wish to make some play dough. A recipe is provided for you.

- 1 cup of flour
- 1 cup of water
- $\frac{1}{4}$ cup of salt
- 1 tablespoon of cooking oil
- 1 tablespoon of cream of tartar

Mix all the ingredients together in a pot and stir constantly over medium heat until the mixture is too thick to stir any longer. Remove the pot from the stove. When the play dough has cooled, remove it from the pot and store it in a sealed plastic container in the refrigerator.

Investigation: Image Formation in Plane Mirrors

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [ ] F. Evaluating

Purpose

In this investigation you will determine how images are formed in plane mirrors.

Materials

- a soft board (corrugated cardboard or ceiling tile – 60 cm by 90 cm)
- small plane mirror (4 cm by 8 cm)
- mirror holder (plasticine or play dough)
- three stick pins
- pencil
- tape
- ruler

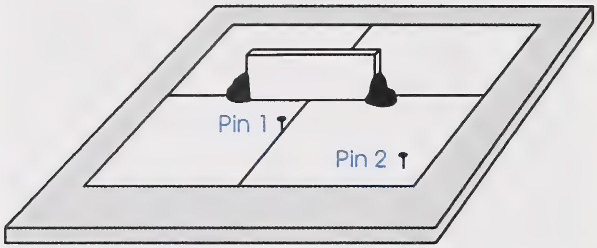
Procedure

- A page showing the correct setup of the mirror and pins is found at the back of the Appendix. Tear out this page and tape it to the soft board. Be sure to tear out the correct page. Check the investigation title printed at the top of the page.

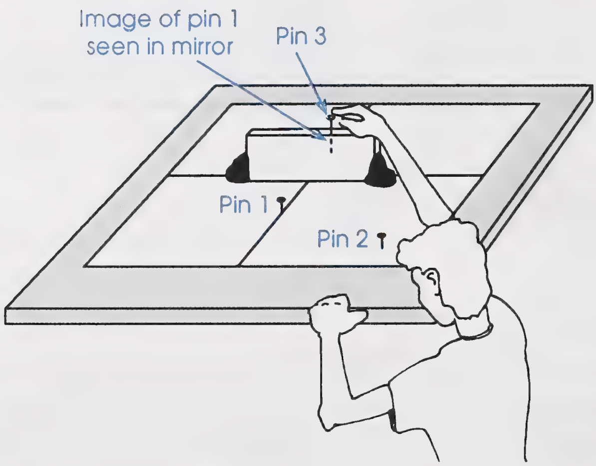
- Place the mirror in an upright position on the line, as shown in the diagram. Hold the mirror in place with plasticine or play dough.

- Place pin 1 at position P_1, as shown.

- Place pin 2 at position P_2, as shown in the following diagram.

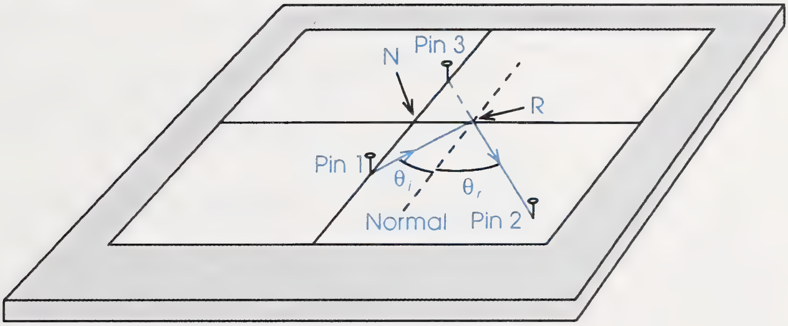


- Look along the plane of the paper and line up pin 2 with the image of pin 1 in the mirror. Then place pin 3 behind the mirror at a position so that all three pins are in line. Mark this position P_3.



- You may find it helpful to realize that the location of pin 3 is actually found through an optical illusion. Since pin 3 is behind the mirror, there is no way that you could really see the bottom of this pin because the mirror is in the way. The illusion is that the reflection of pin 1 makes it appear that pin 3 is complete. However, this only happens when pin 3 is in the correct position behind the mirror.

- You can verify the correct location of pin 3 by moving your head slightly from side to side as you place it behind the mirror.
- Remove the mirror.
- Use a ruler to draw a line connecting P_2 to P_3. The line should be solid from P_2 to the mirror and dotted from the mirror to P_3. Mark the point where the solid line meets the mirror with an R.
- At point R, draw a normal line perpendicular to mirror.



1. Use a protractor to measure θ_i and θ_r. Record these values on the data chart in the Observations and Analysis section.
2. Use a ruler to measure the distance from P_1 to N. This is known as the object distance and it is given the symbol d_o. Record this value on the data chart.
3. Use a ruler to measure the distance from N to P_3. This is known as the image distance and is given the symbol d_i. Record this value on the data chart.

Observations and Analysis

Angles (°)	Distance (cm)
θ_i = ______	d_o = ______
θ_r = ______	d_i = ______

Use this data and your observations to answer the following questions.

virtual image – an image that only appears to be there. No light comes from this image, so it cannot be formed on a screen.

real image – an image that is actually where it appears to be. Light comes from this image, so it can be formed on a screen.

4. When you first observed the image of pin 1 in the mirror, was the image **virtual** or **real**?

5. Is the image in the mirror the same size as the actual pin 1?

6. Is the image in the mirror right-side-up or upside down?

7. Compare d_o and d_i. Is the distance between the image and the mirror the same as the distance between the object and the mirror?

8. Do you think that the image is horizontally reversed? How could you prove this?

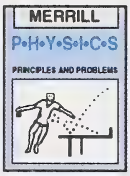
Images are formed whenever light rays meet or converge. A real image is produced when two real light rays converge. A virtual image will form where two virtual rays converge.

9. Was the image that you saw in the mirror at point P_3 real or virtual?

Conclusion

10. How are images in a plane mirror formed?

11. List five properties of the image produced in a plane mirror.



Carefully read pages 368 and 369 of your textbook to learn more about images in plane mirrors.

12. Look at yourself in a plane mirror. Answer these questions about the image.

    a. Is the image virtual?

    b. Is the image the same size as you really are?

    c. Is the image right-side-up?

    d. Is the distance between the image and the mirror the same as the distance between you and the mirror?

    e. Is the image horizontally reversed?

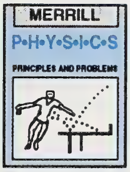
13. Are there any other observable differences between you and your image in the mirror?

14. How big does the mirror have to be for you to see yourself entirely? Explain your answer.

Check your answers by turning to the Appendix, Section 3: Activity 1.

Activity 2: Total Internal Reflection

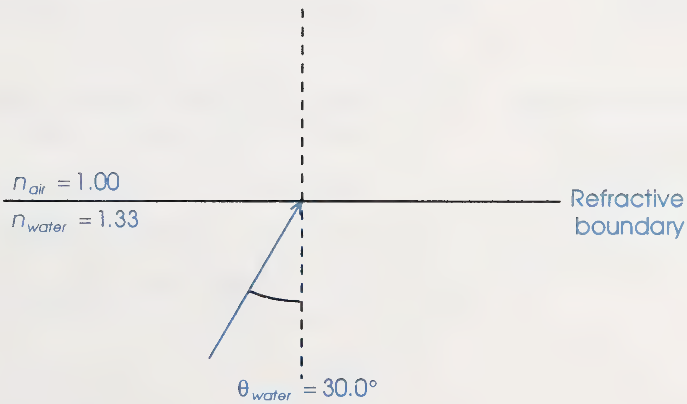
total internal reflection – a type of reflection that occurs when light that is passing from a high density medium to a low density medium reflects back into the high density medium



One application of reflection is the formation of images in plane mirrors. Another application is the effect of **total internal reflection**. When you were doing the investigation called Light Travels from Glass into Air in the previous section, you found a point when no image could be observed. Why? Where did the image go?

This phenomenon inspired one of the most important technological advancements of modern times. The idea began in 1880 when Alexander Graham Bell created an invention called the photophone. The photophone enabled sound energy to be transmitted along light beams. This invention could not be used at the time because of technological inadequacies. The idea arose again about one hundred years later. Could light be transmitted along cables? The dream became a reality with the application of fibre optics. A picture of a fibre optics cable is shown on page 358 of your textbook.

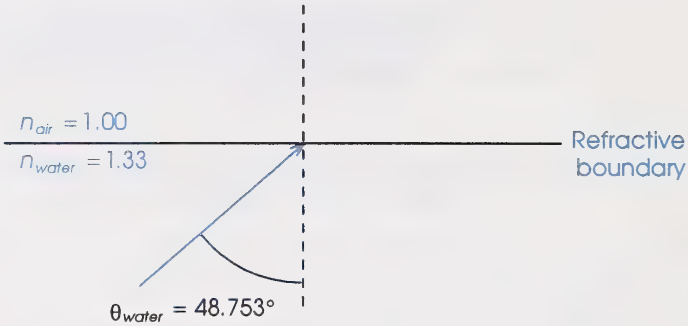
1. To see how the principle of total internal reflection works, study the following diagram and answer the questions that follow.



   a. If a light beam travels from water to air at 30.0°, the refracted beam in air will be at 41.7°. Sketch the refracted ray in the previous diagram.

   b. What do you think will happen to the angle in the air as the angle in the water is increased?

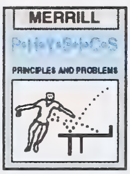
2. a. Use the information from the following diagram to calculate the θ_r in air. Sketch the refracted ray in the diagram.



   b. Where will you observe the refracted ray of light?

3. What do you think would happen in the situation in question 2 if the angle in water was more than 48.75°?

When light travels from a medium with a higher index into a medium with a lower index, a limit is reached where refraction can no longer occur. Beyond this limit the result is called total internal reflection.



Carefully read pages 356 to 358 of your textbook to discover how total internal refraction is a consequence of Snell's law. Be sure to pay particularly close attention to the diagrams and photographs that illustrate the many applications of this concept.

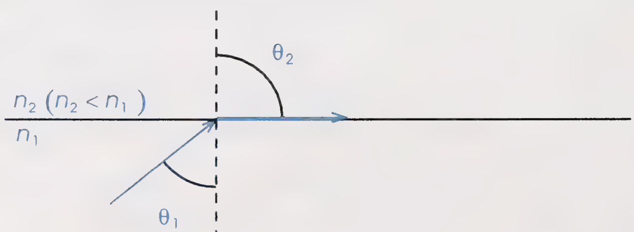
4. What is the incident angle in water called when the refracted angle in air is 90.0°?

5. a. What is the effect called when the incident angle in water is greater than the **critical angle** of water?

   b. Under what conditions can this effect occur?

critical angle – the incident angle in a high density medium at which the angle of refraction in a low density medium will be 90°

The critical angle is unique for every substance and can be calculated using the equation for critical angle. The following flow chart shows that this equation is just a special case of Snell's law.



$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

Substitution

$\theta_1 = \theta_{critical}$

$\theta_2 = 90°$

$$\frac{\sin\theta_{critical}}{\sin 90°} = \frac{n_2}{n_1}$$

Substitution

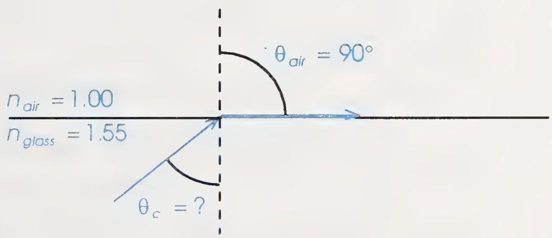
$\sin 90° = 1$

$$\frac{\sin\theta_{critical}}{1} = \frac{n_2}{n_1}$$

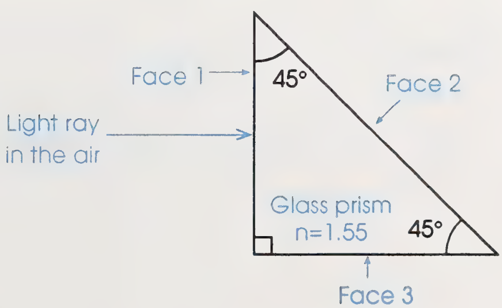
$$\sin\theta_{critical} = \frac{n_2}{n_1}$$

This is the equation for critical angle.

6. Calculate the critical angle for glass. Use the data on the following diagram.



Use the following diagram to answer questions 7 through 9.



7. What will happen to the light ray as it strikes the air-glass boundary at face 1?

8. Draw the light ray passing into glass on the previous diagram.

9. Once the light ray enters the glass prism, it will travel towards face 2. At face 2, it would like to pass through into air.

    a. What is the incident angle of the light ray in glass at face 2?

    b. What is the critical angle for glass at face 2?

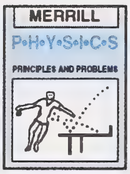
    c. Is the incident angle greater than the critical angle?

    d. What happens at face 2?

    e. Draw the reflected ray.

    f. At what angle will the ray of light hit face 3?

    g. What will happen to this ray of light?

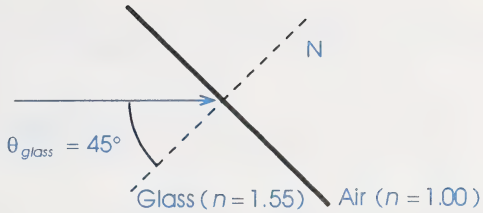


The answers to the previous three questions provide a detailed explanation of how a prism can be used to reflect light. A prism has an advantage over a mirror in that it is more rugged and therefore less likely to become misaligned. This is why prisms are used in binoculars and in periscopes to reflect light. Closely examine Figure 17-9 on page 357 of your textbook to gain some insight about the possible arrangement of the prisms in these devices.

Part c of Figure 17-9 shows how the periscope of a submarine could arrange two prisms to reflect light. The top prism would be above the water level, at the top of the tube. Light enters from the left and is reflected straight down to the submarine. The bottom prism would be near the eyepiece of the periscope inside the submarine. Anyone looking through the eyepiece towards the right face of the prism would then have a view of objects above the surface of the water.

Determining Total Internal Reflection with Your Calculator

Your calculator can be used in an unusual way to save time when solving total internal reflection problems. Imagine that you were asked to determine if total internal reflection occurs in the following situation.



A unique way to solve this problem is to assume that the angle in the air exists and to then try to solve for it using Snell's law. Your calculator will tell you if total internal reflection occurs.

$$\frac{\sin\theta_{air}}{\sin\theta_{glass}} = \frac{n_{glass}}{n_{air}}$$

$$\sin\theta_{air} = \frac{n_{glass}\left(\sin\theta_{glass}\right)}{n_{air}}$$

$$= \frac{(1.55)(\sin 45^\circ)}{(1.00)}$$

$$\sin\theta_{air} = 1.096$$

$$\theta_{air} = \text{undefined (Your calculator will say E for error.)}$$

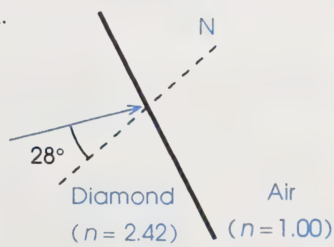
When the value is undefined, total internal reflection occurs.

The calculation proves that there is no angle in the air because the largest possible value for the sine of any angle is 1. Since the value of $\sin\theta_{air}$ is greater than 1, θ_{air} does not exist. From a physics point of view, if the light did not enter the air, it must have reflected and stayed in the glass.

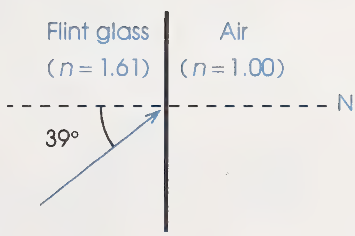
If this technique was applied to the previous question, you could have gone directly from part a to part d without having to do parts b and c.

10. Use your calculator to determine if total internal reflection will occur in each of the following cases.

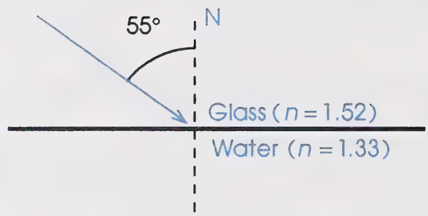
a.



b.



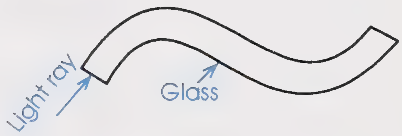
c.



Applications of Total Internal Reflection

You can see that a transparent material like glass can act like a mirror if the incident angle is greater than critical angle of the glass.

Now, consider a piece of optic material, like bent glass or a fiber optic telephone cable.



11. a. Sketch what you think will happen to the light ray as it enters the glass tube.

    b. Could light be transmitted over long distances in this tubing?

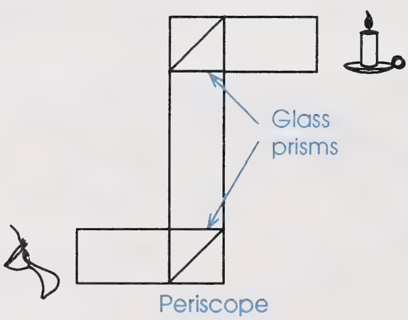
12. a. How is telephone information normally transmitted through a wire?

    b. How can this information now be transmitted along optical fibres?

    c. What is the advantage of optical fibres for transmitting information?

    d. Where else can optical fibres be used?

13. The principle of total internal reflection can also be used in binoculars and periscopes. Look at the following diagram. Light must travel through the periscope from the candle to your eye. Draw the path that the light will take to reach your eye.



Total internal reflection also has applications in medicine. To find out more, read Physics and Technology on page 362 of your textbook and answer the following question.

14. What is the purpose of the illuminating bundle on the device shown on page 362?

These examples have all been the result of total internal reflection, a special case that occurs when light travels from glass to air beyond the critical angle. You will learn about other applications of refraction in the next activity.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Activity 3: Optical Illusions Due to Refraction

Do you ever reach into a shallow pool of water to catch a minnow and wonder why you always seem to miss it? Part of the answer to this problem is that the minnow is not really where it seems to be. The behaviour of light as it passes from water into air creates an optical illusion.

optical illusion – a misleading image presented to the eyes

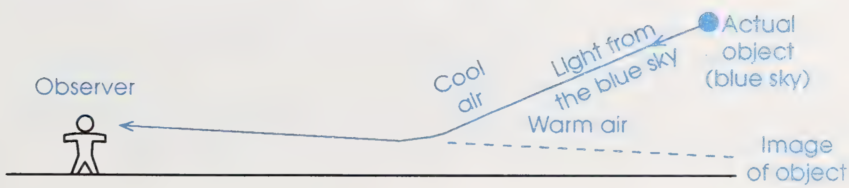
Another example of an optical illusion is the appearance of a mirage. Two photographs that illustrate this effect can be found on page 359 of your textbook. These effects are caused by the refraction of light. In this activity you will study optical illusions and mirages.

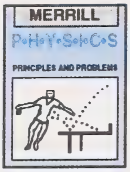
Read pages 358 and 359 in your textbook to answer the following questions.

1. One of the effects of refraction is a mirage. What mirage can be seen along highways in summer?

2. If mirages are caused by the refraction of light, there must be mediums of differing densities. What are the two mediums involved in the formation of a mirage? How are they created?

Examine the diagram of the formation of a mirage.

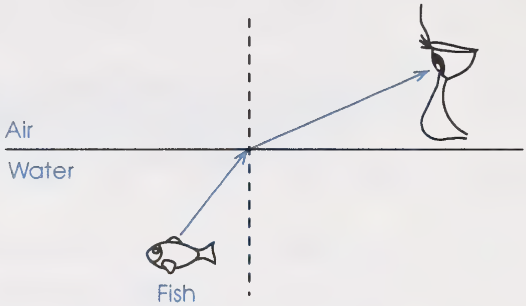




3. Why did the beam of light refract as shown in the previous diagram?

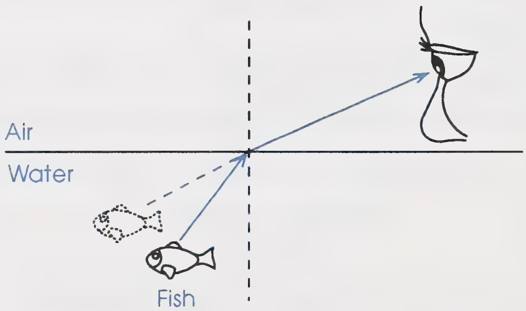
4. If a traveller in a barren desert sees the mirage of a lake, is the light that is going to the traveller's eyes actually coming from the water?

Viewing a fish in a pool of water is also an example of refraction. Light from the fish must travel from the water to your eye, as shown in the following diagram. Use this diagram to answer question 5.



5. Why did the actual ray of light bend away from the normal?

Your eye does not see the bend. It always assumes that light travels in a straight line.



6. If you extend the ray of light along your line of sight with a virtual ray, you only see an image of the fish. This is the fish you were trying to catch. Where should you reach to catch the actual fish?

The two optical illusions discussed in this activity were caused by the refraction of light. There are many other phenomena which are caused by the properties of light. You now have the basic physics to explain many of them. This is a good opportunity to quickly review the main ideas of the entire module.

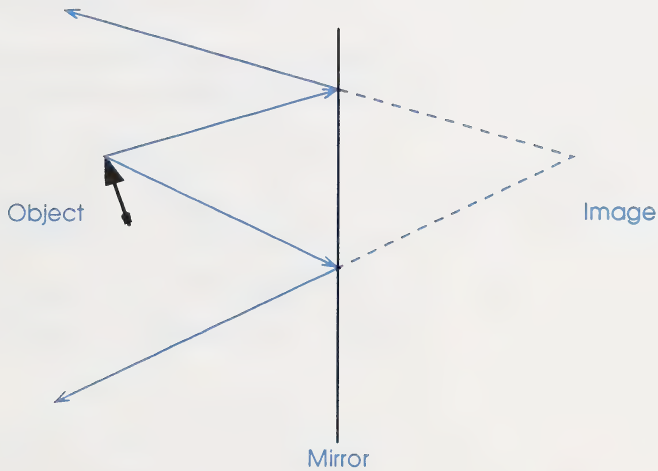
7. Quickly skim through the module booklet and identify the most important new equations that were introduced. Record these equations on the same summary sheet that contains the equations from the other modules. Add any headings or point form explanations to help you use the equations properly.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. The following diagram shows an arrow in front of a mirror. Two light rays leaving the arrow tip indicate how the image of the arrow tip is formed behind the mirror.



   a. Confirm that the two light rays follow the law of reflection by drawing normals and measuring with a protractor.

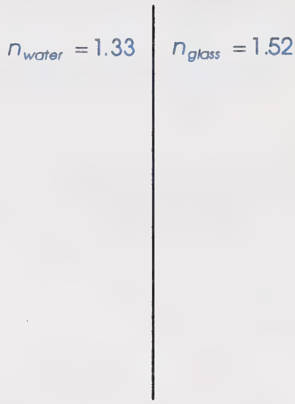
   b. Why are the light rays behind the mirror drawn as dotted lines?

   c. Draw two light rays from the tail of the arrow to the mirror. Use a protractor to draw the reflected rays from the mirror.

   d. Trace the reflected light rays that you drew to locate the image of the tail of the arrow.

e. Fill in the rest of the arrow's image. Is the image the same size and shape as the object?

2. The following diagram shows the boundary between a block of glass and a volume of water.



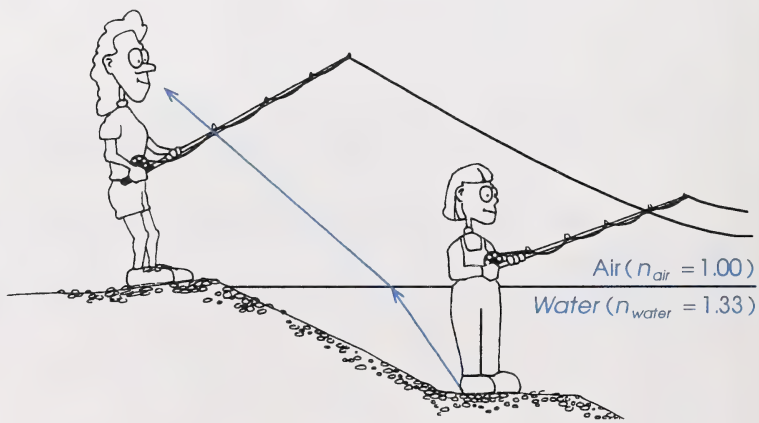
a. To produce a critical angle, must the light travel from the water into the glass, or from the glass into the water?

b. Draw a ray of light that shows the critical angle in one medium and the corresponding angle in the other medium.

c. Calculate the critical angle for this situation.

d. What is so critical about the critical angle?

3. The following diagram shows two people fishing. The person on the shore is looking at the bottom of the other person's boots. Use this diagram to answer the following questions.



a. Draw a normal and use a protractor to measure θ_{water} and θ_{air} on the diagram.

b. Use the general form of Snell's law to verify that this is the way light should behave at the boundary between air and water.

c. Draw where the fisherman on the shore thinks the bottoms of the other fisherman's boots are located.

d. Does the fisherman in the water seem taller or shorter to the fisherman on shore?

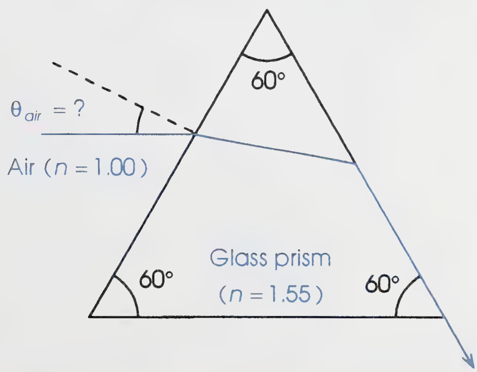
Check your answers by turning to the Appedix, Section 3: Extra Help.

Enrichment

Do **one** of the following activities.

1. If you have access to the booklet called Critical Thinking which accompanies your textbook, turn to page 23 and do the activity for Chapter 17.

2. A beam of light passing through an equilateral glass prism (n=1.55) refracts in along the surface of the glass prism. Calculate the angle of incidence in air for this situation to occur.



Check your answers by turning to the Appedix, Section 3: Enrichment.

Conclusion

In this section you have seen how the law of reflection can be used to explain the images formed in plane mirrors. You have also learned that reflection can take place at a refractive boundary if the incident angle exceeds the critical angle. Refraction can also be used to explain a variety of optical illusions, such as mirages and displaced images in water.

The wave nature of light has many other interesting applications which you will examine in the next module.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 3.

MODULE SUMMARY

In this module you were introduced to the concept of light and its many unique and interesting properties. You then began an analysis of some of these properties. Finally, you applied these properties to some phenomena that occur in everyday life.

You now have the basics to understand light and its powerful impact on science, society, and technology. It is hard to image anything in life that does not involve light.

In the next module you will complete your study of light by investigating the interesting properties of curved mirrors and lenses. You will also have an opportunity to explore the diffraction and interference of light.

Appendix

Glossary

Activities

Extra Help

Enrichment

Glossary

critical angle – the incident angle in a high density medium at which the angle of refraction in a low density medium will be 90°

dispersion – the spreading of white light into the full spectrum of colours

normal – an imaginery line drawn perpendicularly (at 90°) to a point on a surface where the light beam strikes

opaque – a property that does not allow light to pass through a material

optical illusion – a misleading image presented to the eyes

polarizing material – a material that has long molecules that permit transverse waves vibrating in one plane to pass through

propagation – the act of travelling from one place to another

real image – an image that is actually where it appears to be. Light comes from this image, so it can be formed on a screen.

Snell's Law – $\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$

total internal reflection – a type of reflection that occurs when light that is passing from a high density medium to a low density medium reflects back into the high density medium

translucent – a property that allows light to pass through a material, but does not permit objects to be clearly seen through the material

transparent – a property that allows light to pass through a material and permits objects to be clearly seen through the material

virtual image – an image that only appears to be there. No light comes from this image, so it cannot be formed on a screen.

Suggested Answers

Section 1: Activity 1

1. The Aztec civilization of South America worshipped this sun god.

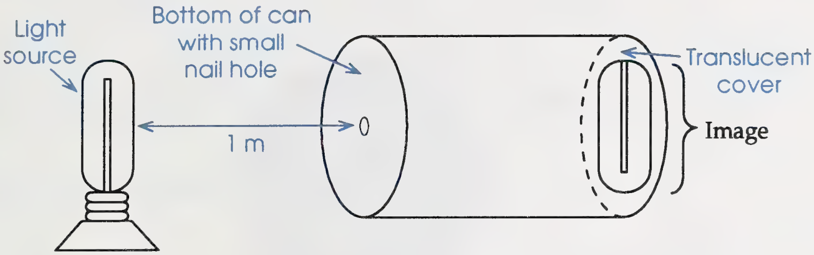
2. Answers may vary. For example, if you think light travels as a wave, you might justify this by giving an example involving refraction, diffraction, interference, colours, dispersion, or polarization. If you think light travels as a particle, you might justify this by giving an example involving propagation or reflection.

3. Both theories suggest that light travels at a high speed and that light travels in a straight line.

4. a. reflection
   b. refraction
   c. diffraction or interference
   d. colour
   e. dispersion

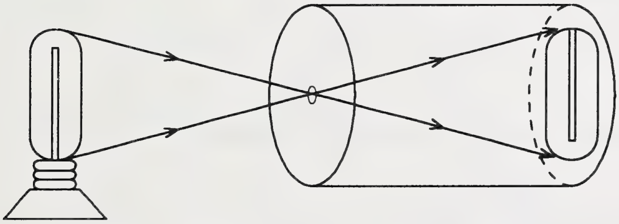
Section 1: Activity 2

1.



2. The image is upside down (vertically reversed).

3.

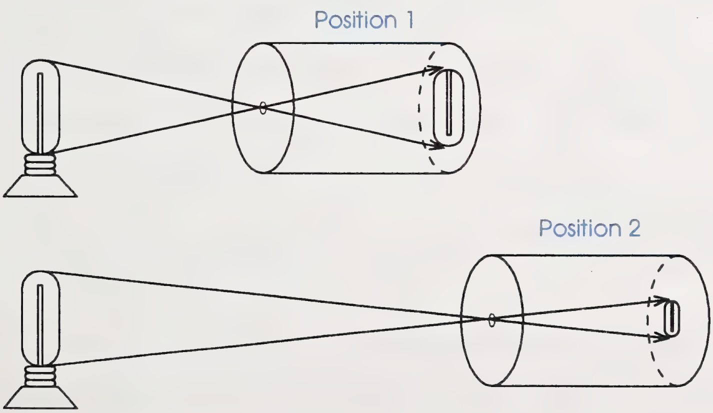


4. Yes, the rays explain why the image is upside down. They prove that light must travel in a straight line if the image is vertically reversed.

5. Yes, the image is reversed right to left. To prove this, mark a dot on the right side of the light bulb and observe that the dot appears on the left side of the image.

6. The image should have become smaller and dimmer as you moved the coffee can away from the light source.

7.

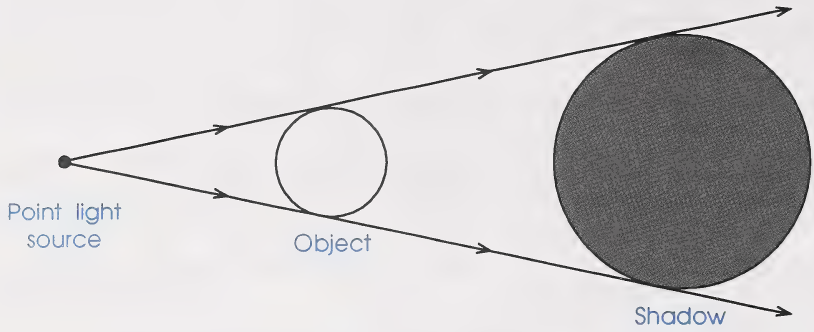


8. Light must travel in a straight line.

9. The image would be formed upside down on the retina, but the brain interprets it right-side-up.

10. Answers may vary. One example is the fact that you cannot see objects around corners. Another example is the formation of shadows.

11.



Section 1: Activity 3

1. Before the seventeenth century, most people believed that light travels instantaneously.

2. Galileo was the first to suggest a finite speed for light.

3. His method was not sensitive enough to measure the time taken for light to travel such a small distance (a few kilometres).

4. There is no way of improving his method to obtain a value for the speed of light using Galileo's equipment. The distance required to obtain a reading of time is too great for measurements with candles and water clocks.

5. This must be the time taken for light to travel the diameter of Earth's orbit.

6. $d = 3.0 \times 10^{11}\ \text{m}$

   $t = 22\ \text{min} = 1320\ \text{s}$

   $v = ?$

$$v = \frac{d}{t}$$

$$v = \frac{3.0 \times 10^{11}\ \text{m}}{1320\ \text{s}}$$

$$= 2.3 \times 10^{8}\ \text{m/s}$$

7. speed of light $= 2.997\,996 \pm 0.000\,04 \times 10^{8}\ \text{m/s}$

8. There were two errors in his measurements.

   - The time taken was 16 min, not 22 min.
   - Earth's orbital diameter is actually greater than $3.0 \times 10^{11}\ \text{m}$.

9. Roemer was working on a project to improve maps by calculating the longitudes of locations on Earth by observing simultaneous eclipses of Jupiter's moon, Io.

10. Using a laser and assuming that light is a wave, scientists use the formula $c = f\lambda$ where c is the speed of light, f is the frequency, and λ is the wavelength. The frequency and wavelength of the laser are measured and the speed of light is calculated.

11. $f = 5.40 \times 10^{14}\ \text{Hz}$ $\qquad c = f\lambda$

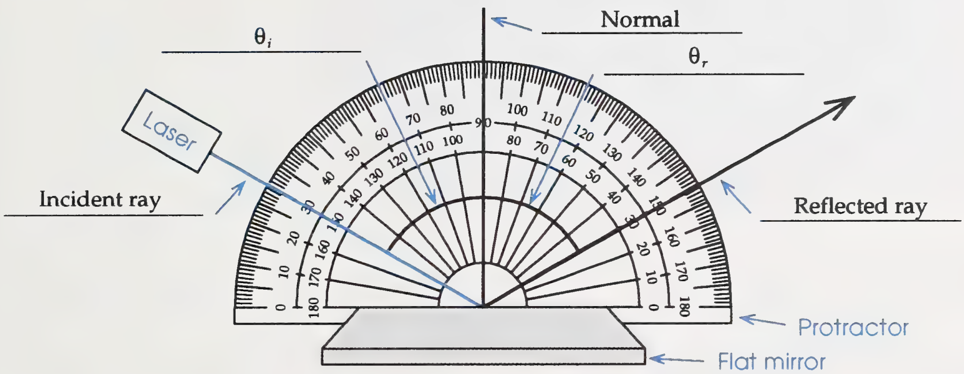
$\lambda = 5.56 \times 10^{-7}\ \text{m}$ $\qquad = (5.40 \times 10^{14}\ \text{Hz}) \times (5.56 \times 10^{-7}\ \text{m})$

$c = ?$ $\qquad = 3.00 \times 10^{8}\ \text{m/s}$

12. No. Both particles and waves can travel in a straight line and at a high speed.

Section 1: Activity 4

1.



2. Question 2 is answered on the previous diagram.

3. Question 3 is answered on the previous diagram.

4. The angle of incidence is 60°.

5. The angle of reflection is 60°.

6. The law of reflection states that the angle of incidence equals the angle of reflection.

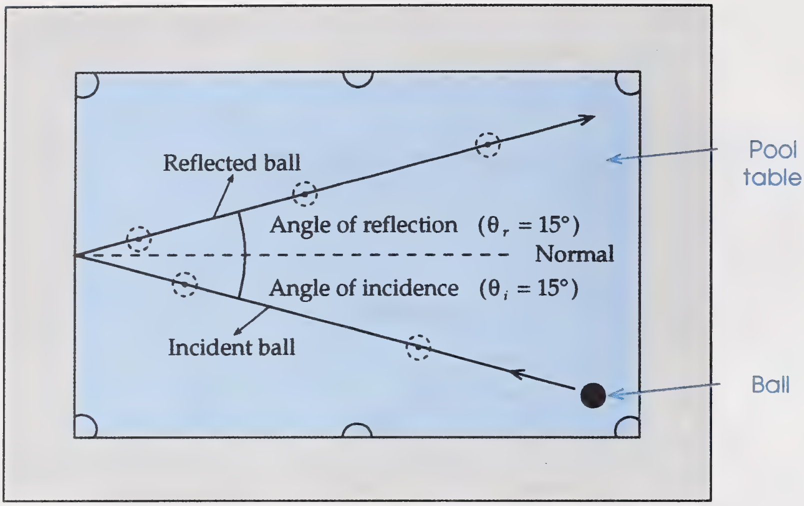
7. When a beam of light reflects off a shiny surface, it reflects so that it obeys the law of reflection ($\theta_i = \theta_r$).

8. Regular reflection occurs when a beam of light strikes a flat shiny surface and obeys the law of reflection.

9. Diffuse reflection occurs when a beam of light strikes an irregular surface, causing the beam of light to reflect in many directions. Each individual ray still obeys the law of reflection. Note that the normal is always perpendicular to the surface.

10. Yes, both types of reflection obey the law of reflection. The main difference is that in regular reflection, the rays remain parallel after they reflect because of the smooth uniform surface.

11.



12. This question is answered on the previous diagram.

13. Yes, particles obey the law of reflection.

14. Yes, waves follow the law of reflection.

Section 1: Follow-up Activities

Extra Help

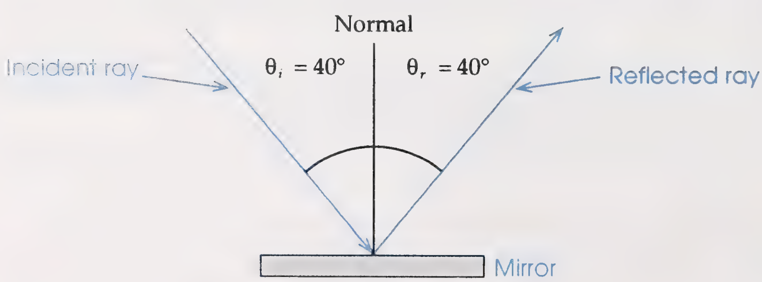
1. Newton proposed that light travels as a particle in a straight line at high speed.

   Huygens proposed that light travels as a wave in a straight line at high speed.

2. Your drawing could be of any one of the following things.

   - a drawing of an image being formed upside down in a pinhole camera
   - a drawing showing that you can't see objects around corners
   - a drawing of the formation of a shadow

3.



The angle of reflection is 40°.

4. Both the wave theory and the particle theory explain both properties.

5. These questions are answered on page 677 of your textbook.

Enrichment

1. a. $d = 2\left(3.50 \times 10^4 \text{ m}\right)$

$= 7.00 \times 10^4 \text{ m}$

$= 70.0 \text{ km}$

b. A distance of 1 m is insignificant compared to the 70.0 km round trip of the light beam. The distance would only be significant if the other measurements were made to a precision of five significant digits.

c. $f = \dfrac{536 \text{ rotations}}{1 \text{ s}} = 536 \text{ Hz}$

$T = \dfrac{1}{f} = \dfrac{1}{536 \text{ Hz}} = 1.866 \times 10^{-3} \text{ s}$

The mirror takes 1.866×10^{-3} s to make one rotation. The time for one-eighth of a rotation can be calculated as follows:

$$\frac{T}{8} = \frac{1.866 \times 10^{-3} \text{ s}}{8} = 2.332 \times 10^{-4} \text{ s}$$

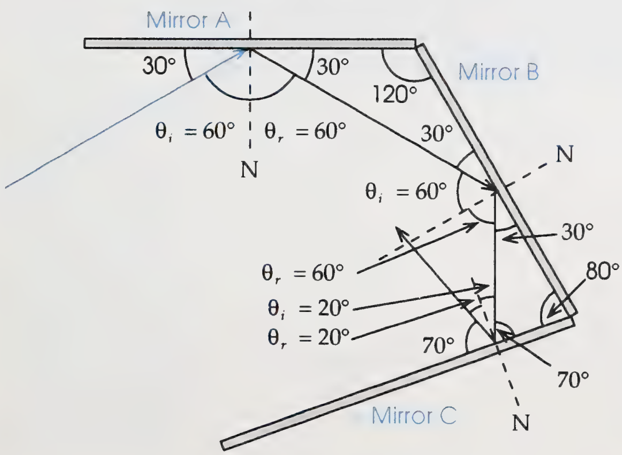
d. $t = 2.332 \times 10^{-4} \text{ s}$

$d = 7.00 \times 10^4 \text{ m}$

$v = ?$

$$v = \frac{d}{t} = \frac{7.00 \times 10^4 \text{ m}}{2.332 \times 10^{-4} \text{ s}} = 3.00 \times 10^8 \text{ m/s}$$

2.



The beam of light reflects at an angle of 70° to mirror C or $\theta_r = 20°$ to the normal.

3. a. If two mirrors are at 180°, there are two quadrants being formed in a full circle of 360°. Since the object occupies one quadrant, the number of possible images is one. If two mirrors are at 90°, there are four quadrants created with three possible images. Therefore, if two mirrors are at 45°, seven images are possible.

   b. $n = \frac{360°}{\theta} - 1$ $\quad$ n = number of images

   θ = angle between two flat mirrors

Section 2: Activity 1

1. a. The ancient Greeks contributed the following ideas:

   - Light consists of high speed particles that travel in a straight line.
   - The law of reflection describes light.
   - The inverse square law for intensity describes light.

   b. Galileo contributed the idea that light has a finite speed.

   c. Huygens originated the wave theory of light and the idea that any point along a place wave front could be a source for waves.

   d. Maxwell contributed the idea that light is energy that is carried by electric and magnetic fields.

   e. Einstein contributed the idea that light consists of little bundles of energy called photons.

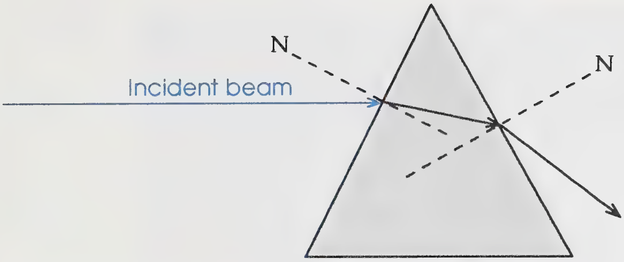
2. Light transfers energy.

3. A photomultiplier detects and records the number of photons.

4.

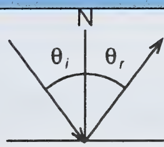
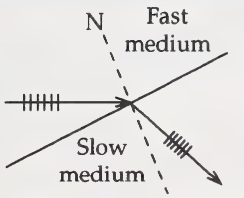
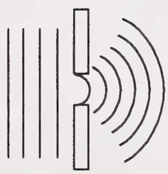
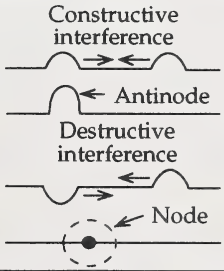
Comparing Light from a Flashlight and a Laser		
Characteristics	**White Light from a Flashlight**	**Laser Light**
Coherent or Incoherent	incoherent light	coherent light
Description of Photons Emitted	Photons of many frequencies and phases are present.	Photons with the same frequency and phase form a stream in the same direction.
Description of Beam Produced	The beam becomes wider and less intense.	The beam diverges very little and maintains a high intensity.

5.



6. Other than reflection and refraction, light also exhibits diffraction, interference, and polarization.

7.

Evidence of Light Acting as a Wave in Photographs			
Wave Property	**Description of the Property**	**Diagram of the Property**	**Textbook Pages**
Reflection	Waves reflect from a boundary such that $\theta_i = \theta_r$.		348, 349, 350, 370, 375, 377
Refraction	Waves can change direction due to a difference in speed between two media.		337, 346, 349, 350, 351, 357, 359, 380
Diffraction	Waves can spread out when they pass through an opening that is the same size or smaller than λ.		393, 396, 398, 400, 401, 402
Interference	When waves meet, they can combine constructively or destructively, according the principle of superposition.		337, 340, 393, 398, 401, 402

8. This question is answered on the previous chart.

9. Table 1

θ_{air}	θ_{glass}	θ_{air}	θ_{glass}
0.0°	0.0°	50.0°	30.7°
10.0°	6.7°	60.0°	35.3°
20.0°	13.2°	70.0°	38.8°
30.0°	19.5°	80.0°	41.0°
40.0°	25.4°	90.0°	41.8°

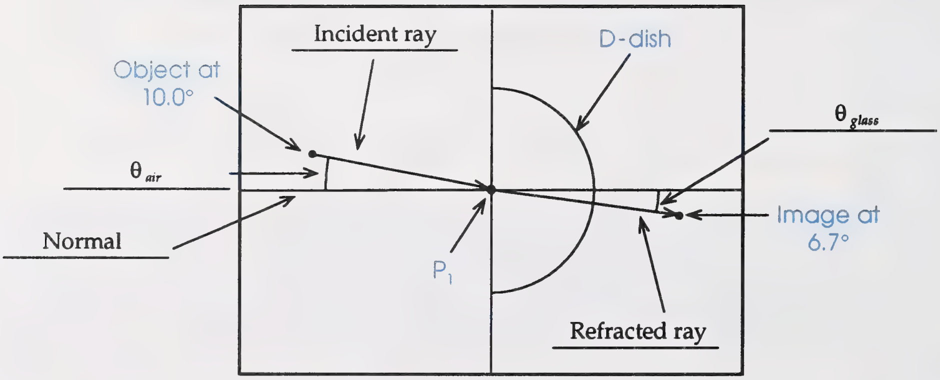
10. This question is answered on the previous chart.

11. When the object was at 0° (on the normal), the ray passing through glass appeared at 0° (on the normal).

12. It appeared to bend.

13. It bent towards the normal.

14.



15. The light bent at the air-glass boundary at the flat side.

16. The ray of light hits the curved side at 90° to the boundary, so no bending occurs. The situation is similar to the analogy of the marching band that you developed in Module 5. If a row of marchers encountered knee-deep snow while marching at 90° to the boundary, they would all slow down, but there would be no change in direction since they all strike the boundary at the same time.

17. When passing from a less dense medium to a more dense medium, light rays bend towards the normal.

18. Table 2

θ_{glass}	θ_{air}	θ_{glass}	θ_{air}
0.0°	0.0°	**50.0°**	no image
10.0°	15.1°	**60.0°**	no image
20.0°	30.9°	**70.0°**	no image
30.0°	48.5°	**80.0°**	no image
40.0°	74.6°	**90.0°**	no image

19. Answers are shown on the previous chart.

20. When the object was at 0° (on the normal), the ray passing through the air appeared at 0° (on the normal).

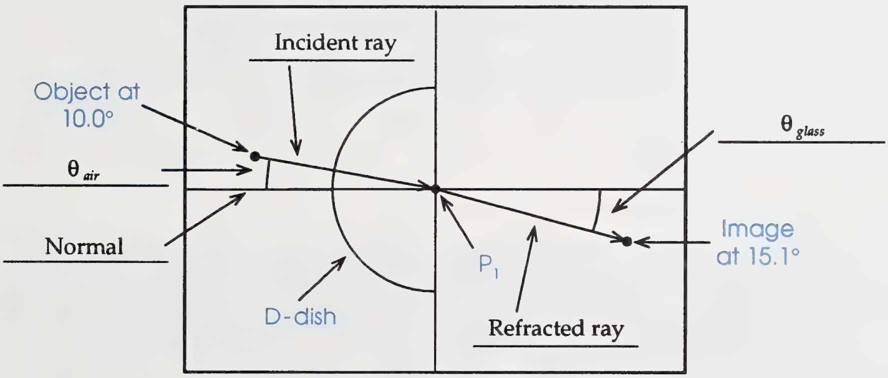
21. It appeared to bend.

22. It disappeared at an angle slightly less than 50°.

23. It is reflecting off the flat glass-air boundary back into the glass.

24. It bent away from the normal.

25.



26. It occurred on the flat side.

27. The light rays bend away from the normal.

Section 2: Activity 2

1. This is called refraction.

2. As the car enters the mud, the left wheels slow down before the right wheels, causing the car to deflect towards the normal. The same can be said of the incident ray of light which bends toward the normal due to the speed slowing down.

3. As the car enters the pavement, the right wheels speed up before the left wheels, causing the car to deflect away from the normal. For the light ray in the other part of the diagram, there is also a bending away from the normal due to an increase in speed.

4. a. Light must slow down and bend towards the normal when passing from air into glass.

   b. Light must speed up and bend away from the normal when passing from glass into air.

5. No, light does not travel at the same speed in all media. As the density of the medium increases, the speed of light must decrease.

6.

Data for Light Travelling from Air into Glass

Position	θ_{air}	θ_{glass}	$\sin \theta_{air}$	$\sin \theta_{glass}$	$\frac{\sin \theta_{air}}{\sin \theta_{glass}}$
1	0.0°	0.0°	0.0000	0.0000	undefined
2	10.0°	6.7°	0.1736	0.1167	1.49
3	20.0°	13.0°	0.3420	0.2250	1.50
4	30.0°	19.5°	0.5000	0.3338	1.50
5	40.0°	25.5°	0.6428	0.4305	1.49
6	50.0°	30.5°	0.7660	0.5075	1.51
7	60.0°	35.5°	0.8660	0.5807	1.49
8	70.0°	39.0°	0.9397	0.6293	1.49
9	80.0°	41.0°	0.9848	0.6561	1.50
10	90.0°	42.0°	1.0000	0.6691	1.49

7. The average of these values is 1.50.

8.

Data for Light Travelling from Glass into Air					
Position	θ_{glass}	θ_{air}	$\sin\theta_{glass}$	$\sin\theta_{air}$	$\frac{\sin\theta_{glass}}{\sin\theta_{air}}$
1	0.0°	0.0°	0.0000	0.0000	undefined
2	10.0°	15.0°	0.1736	0.2588	0.671
3	20.0°	30.0°	0.3420	0.5000	0.684
4	30.0°	48.5°	0.5000	0.7490	0.666
5	40.0°	75.0°	0.6428	0.9659	0.665

9. The average of the values is 0.672.

10. The average value of 0.672 is nearly the reciprocal of 1.50 ($\frac{1}{0.672} = 1.49$).

11. You could have plotted a $\sin\theta_i$ versus $\sin\theta_r$ graph and the slope of the line would have yielded the same average value.

12. a. The constant n is called the index of refraction.

    b. The entire equation is called Snell's law.

13. Snell's law would be written as follows.

$$n_{glycerine} = \frac{\sin\theta_{air}}{\sin\theta_{gylcerine}}$$

14.

Data for Light Travelling from Air into Water					
Position	θ_{air}	θ_{water}	$\sin\theta_{air}$	$\sin\theta_{water}$	n_{water}
1	0.0°	0.0°	0.0000	0.0000	undefined
2	10.0°	7.2°	0.1736	0.1253	1.39
3	20.0°	15.5°	0.3420	0.2672	1.28
4	30.0°	22.0°	0.5000	0.3746	1.33
5	40.0°	29.0°	0.6428	0.4848	1.33

Average = 1.33

15.

	Light Travelling from Air into Water	Light Travelling from Air into Glass
Index of Refraction	1.33	1.50

16. a. $n_{water} = 1.33$ b. $n_{crown\ glass} = 1.52$ c. $n_{diamond} = 2.42$

17. a. The angle of refraction in diamond would be much smaller than the angle of incidence in air.

b. The speed of light in diamond would be much slower than in air.

18. a. n_1 – the index of refraction for the first medium

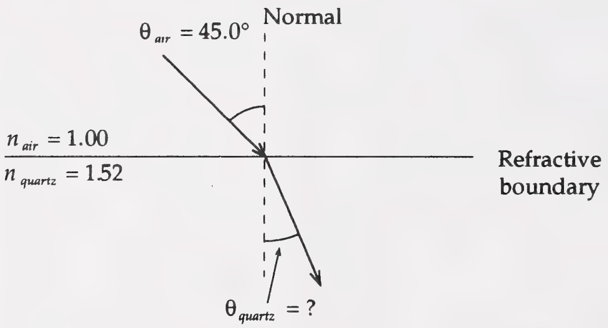
b. θ_1 – the angle to the normal in the first medium

c. n_2 – the index of refraction for the second medium

d. θ_2 – the angle to the normal in the second medium

19. He developed a method of measuring distances using trigonometry and this led to modern map making.

20.



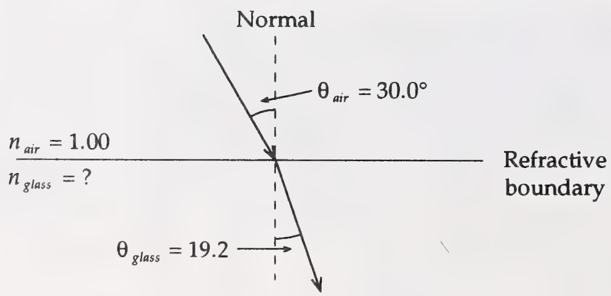
$$\frac{\sin\theta_{air}}{\sin\theta_{quartz}} = \frac{n_{quartz}}{n_{air}}$$

$$\sin\theta_{quartz} = \frac{n_{air}\left(\sin\theta_{air}\right)}{n_{quartz}} = \frac{(1.00)(\sin 45.0°)}{(1.52)}$$

$$\sin\theta_{quartz} = 0.4652$$

$$\theta_{quartz} = 27.7°$$

21.



$$\frac{\sin\theta_{air}}{\sin\theta_{glass}} = \frac{n_{glass}}{n_{air}}$$

$$n_{glass} = \frac{n_{air}\left(\sin\theta_{air}\right)}{\sin\theta_{glass}} = \frac{(1.00)(\sin 30.0°)}{(\sin 19.2°)} = 1.52$$

22. The answers to these problems are found on pages 677 and 678 of your textbook.

23. Yes, both theories explain that the angle of incidence must equal the angle of reflection.

24. No, you can't use reflection because both theories have the same predicted behaviour for light.

25. In the particle theory, the particle travels faster in medium 2. In the wave theory, the wave travels slower in medium 2.

26. Yes, refraction can be used because each theory predicts a different speed change in the second medium.

27. Huygens' wave theory is best. Since light slows down in medium 2 and waves do the same, light is a wave.

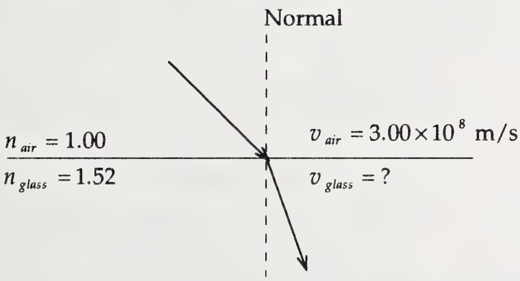
28. a. n_1 – index of refraction of the incident medium

b. n_2 – index of refraction of the refractive medium

c. v_1 – speed in the incident medium

d. v_2 – speed in the refractive medium

29.



$$\frac{v_{air}}{v_{glass}} = \frac{n_{glass}}{n_{air}}$$

$$v_{glass} = \frac{n_{air}\, v_{air}}{n_{glass}}$$

$$= \frac{(1.00)(3.00 \times 10^8 \text{ m/s})}{1.52}$$

$$= 1.97 \times 10^8 \text{ m/s}$$

30. The answers to these problems are found on page 678 of your textbook.

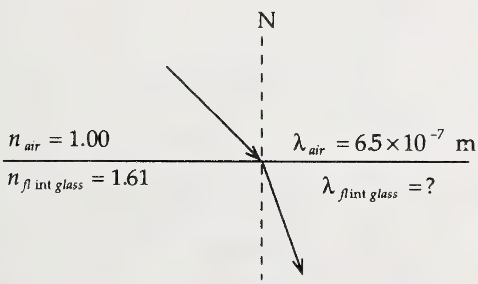
31. a. n_1 – the index of refraction for the first medium

b. λ_1 – the wavelength of the light in the first medium

c. n_2 – the index of refraction for the second medium

d. λ_2 – the wavelength of the light in the second medium

32.



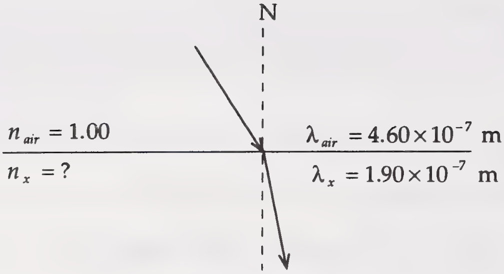
$$\frac{\lambda_{air}}{\lambda_{flint\ glass}} = \frac{n_{flint\ glass}}{n_{air}}$$

$$\lambda_{flint\ glass} = \frac{n_{air}\, \lambda_{air}}{n_{flint\ glass}}$$

$$= \frac{(1.00)(6.50 \times 10^{-7} \text{ m})}{(1.61)}$$

$$= 4.04 \times 10^{-7} \text{ m}$$

33. a.

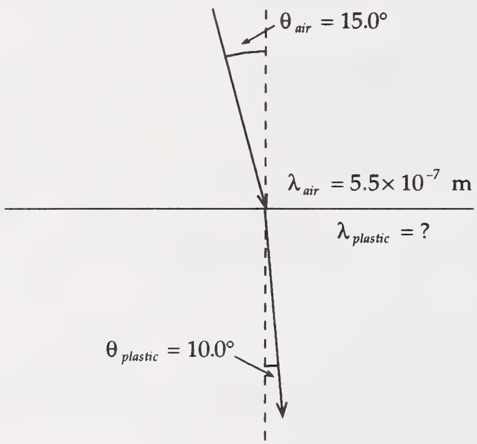


$$\frac{\lambda_{air}}{\lambda_x} = \frac{n_x}{n_{air}}$$

$$\begin{aligned} n_x &= \frac{n_{air}\lambda_{air}}{\lambda_x} \\ &= \frac{(1.00)(4.60 \times 10^{-7}\ \text{m})}{(1.90 \times 10^{-7}\ \text{m})} \\ &= 2.42 \end{aligned}$$

b. According to Table 17-1 on page 353 of the textbook, substance x must be diamond.

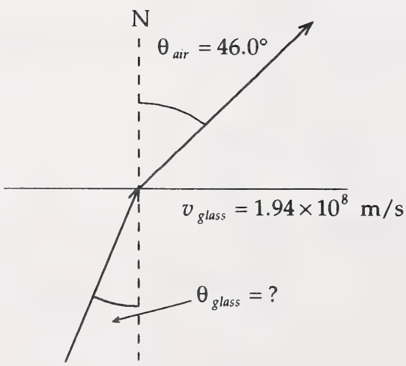
34.



$$\frac{\sin\theta_{air}}{\sin\theta_{plastic}} = \frac{\lambda_{air}}{\lambda_{plastic}}$$

$$\begin{aligned} \lambda_{plastic} &= \frac{\sin\theta_{plastic}\,\lambda_{air}}{\sin\theta_{air}} \\ &= \frac{(\sin 10.0°)(5.5 \times 10^{-7}\ \text{m})}{(\sin 15.0°)} \\ &= 3.7 \times 10^{-7}\ \text{m} \end{aligned}$$

35.



Recall that the speed of light in air is $3.00 \times 10^8\ \text{m/s}$.

$$\frac{\sin\theta_{air}}{\sin\theta_{glass}} = \frac{v_{air}}{v_{glass}}$$

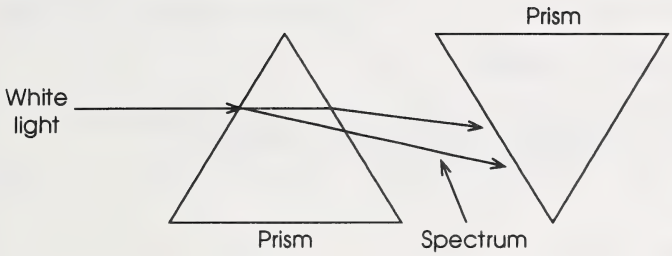
$$\begin{aligned} \sin\theta_{glass} &= \frac{\sin\theta_{air}(v_{glass})}{v_{air}} \\ &= \frac{(\sin 46.0°)(1.94 \times 10^8\ \text{m/s})}{(3.00 \times 10^8\ \text{m/s})} \\ \sin\theta_{glass} &= 0.4652 \\ \theta_{glass} &= 27.7° \end{aligned}$$

Section 2: Activity 3

1. Newton called this a spectrum.

2. He thought irregularities in the glass produced the spectrum.

3. a.



   b. If the spectrum was formed by irregularities in the glass, the second prism should cause the spectrum to separate more.

   c. The second prism converged the spectrum into white light.

   d. The colours were present in the original white light.

4. The wavelength range for visible light is 400 nm to 700 nm. Another way to express this is 4×10^{-7} m to 7×10^{-7} m.

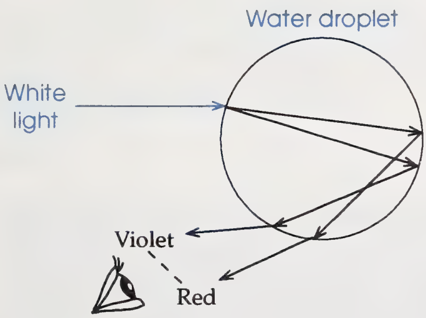
5. Violet has the shortest wavelength.

6. Red has the longest wavelength.

7. Red slows down the least as it enters the glass because it bends the least.

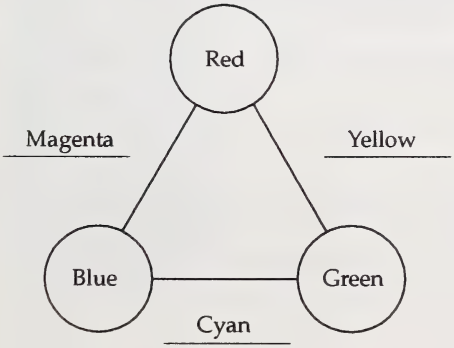
8. Violet slows down the most as it enters the glass because it bends the most.

9.



As white light enters the water droplet, it refracts and disperses into colours. As it strikes the opposite end of the water droplet, it reflects back due to total internal reflection. It then passes through the water droplet as shown and further disperses and forms a rainbow.

10.



11. The three primary colours produce white light.

12. This question is answered on the previous diagram.

13. Yellow is complementary to blue. Since yellow is a mixture of red and green, when you add yellow and blue, you are really adding green, red, and blue, which gives you white light.

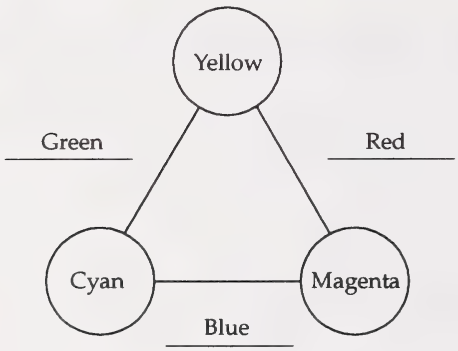
14. a. Red light is reflected to your eye.

    b. The book absorbs all the other colours.

15. This is called the subtractive colour theory of light.

16. A dye is a molecule that absorbs certain colours and reflects others. A pigment is a particle (much larger than a molecule) that can absorb certain colours and reflect all others.

17.



18. The primary colours of the additive theory are the secondary colours of the subtractive theory. The primary colours of the subtractive theory are the secondary colours of the additive theory.

Section 2: Activity 4

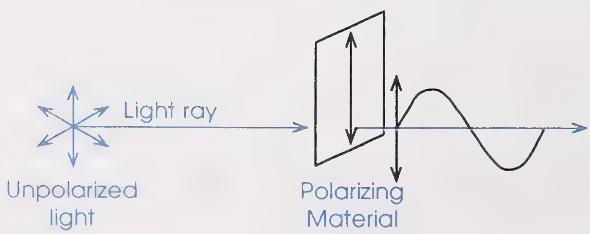
1. The light transmitted alternated between being brighter and darker.

2. There was no change in the brightness of light.

3. As you rotate one of the filters, the transmitted light will get dimmer and then become completely black. Continuing to rotate the filter will cause the transmitted light to become brighter.

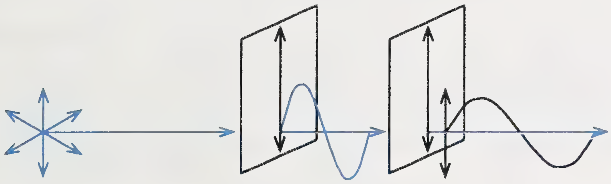
4. Normal light vibrates in all the directions that are perpendicular to its direction of travel.

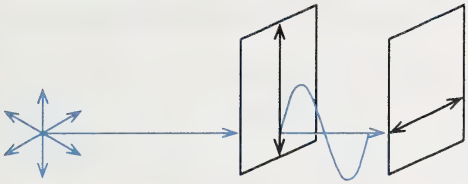
5.



6. It is light that is vibrating in only one plane.

7.





8. The second filter is called an analyser.

9. No, only transverse waves can be polarized, since being polarized requires that the wave vibrate in one plane. Longitudinal waves and particles do not vibrate in a plane.

10. It proves that light is a transverse wave.

11. Light from the sun can be polarized in the following ways:

- reflection from flat surfaces
- scattering off dust particles in the atmosphere

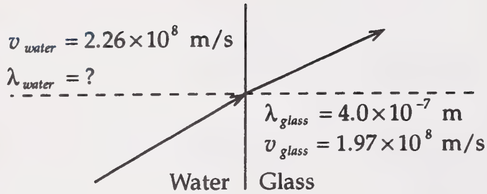
Section 2: Follow-up Activities

Extra Help

1.

Factor of Light	How does this factor change as it passes from a low density to a high density medium?	How does this factor change as it passes from a high density to a low density medium?
Speed	The speed is reduced.	The speed increases.
Direction	The light bends towards the normal.	The light bends away from the normal.
Wavelength	The wavelength decreases.	The wavelength increases.
Frequency	Frequency is not changed.	Frequency is not changed.

2. a.



b.
$$\frac{v_{water}}{v_{glass}} = \frac{\lambda_{water}}{\lambda_{glass}}$$
$$\lambda_{water} = \frac{v_{water}\lambda_{glass}}{v_{glass}}$$
$$= \frac{(2.26 \times 10^8 \text{ m/s})(4.0 \times 10^{-7} \text{ m})}{1.97 \times 10^8 \text{ m/s}}$$
$$= 4.6 \times 10^{-7} \text{ m}$$

c. Step 1: Find the frequency of the light.

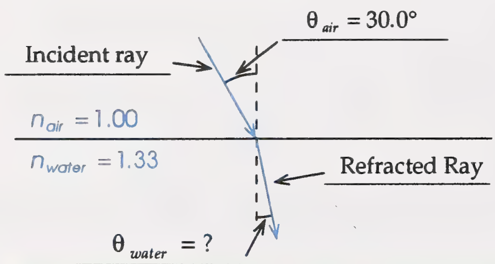
$$v_{glass} = \lambda_{glass} f$$
$$f = \frac{v_{glass}}{\lambda_{glass}}$$
$$= \frac{1.97 \times 10^8 \text{ m/s}}{4.0 \times 10^{-7} \text{ m}}$$
$$= 4.925 \times 10^{14} \text{ Hz}$$

Step 2: Find the wavelength in the water.

$$v_{water} = \lambda_{water} f$$
$$\lambda_{water} = \frac{v_{water}}{f}$$
$$= \frac{2.26 \times 10^8 \text{ m/s}}{4.925 \times 10^{14} \text{ Hz}}$$
$$= 4.6 \times 10^{-7} \text{ m}$$

The frequency is the same in both water and glass.

3. a.



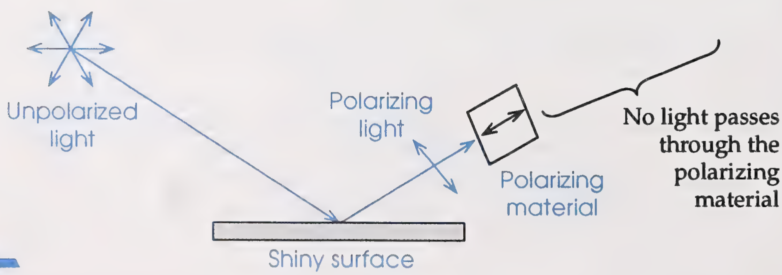
b.
$$\frac{\sin\theta_{air}}{\sin\theta_{water}} = \frac{n_{water}}{n_{air}}$$
$$\sin\theta_{water} = \frac{n_{air}\sin\theta_{air}}{n_{water}}$$
$$= \frac{(1.00)(\sin 30.0°)}{(1.33)}$$
$$= 22.1°$$

4. a.

Theory	What are its primary colours?	What are its secondary colours?
Additive	red, blue, green	yellow, magenta, cyan
Subtractive	yellow, magenta, cyan	red, blue, green

b. All colours are absorbed, no colours are reflected.

5. a.



b. Nothing would be seen through this filter.

Enrichment

1. Answers to this activity can be found in the teacher's section at the back of the Enrichment booklet.

2. The following derivation uses Figure 17-7 from page 354 of your textbook. Note that θ_i can also be called θ_{air} and θ_r can be called θ_{glass}.

   - Line CB is an approaching wavefront.
   - The time that ray x travels from B to A, ray y must also travel from C to D.

   The first stage of the derivation is to relate the geometry of the triangles to the speed of the wave in both media.

   - For ray x:

   $$v_{air} = \frac{d_{air}}{t} = \frac{BA}{t}$$

   $$t = \frac{BA}{v_{air}}$$

   - For ray y:

   $$v_{glass} = \frac{d_{glass}}{t} = \frac{CD}{t}$$

   $$t = \frac{CD}{v_{glass}}$$

   Since the times are the same, these two equations can be combined to form equation 1.

   $$\frac{BA}{v_{air}} = \frac{CD}{v_{glass}} \qquad \text{Equation 1}$$

   The next stage in the derivation is to relate the segments BA and CD to the angles in air and glass.

   - $\theta_{air} = \theta_i = \theta_1$

   Therefore:

   $$\sin\theta_{air} = \sin\theta_i = \sin\theta_1 = \frac{BA}{CA}$$

   $$BA = \sin\theta_{air}\,(CA) \qquad \text{Equation 2}$$

   - $\theta_{glass} = \theta_r = \theta_2$

   Therefore:

   $$\sin\theta_{glass} = \sin\theta_r = \sin\theta_2 = \frac{CD}{CA}$$

   $$CD = \sin\theta_{glass}\,(CA) \qquad \text{Equation 3}$$

   The final stage of the derivation is to combine Equations 1, 2, and 3.

   - Substitute Equations 2 and 3 into Equation 1.

   $$\frac{[BA]}{v_{air}} = \frac{[CD]}{v_{glass}}$$

   $$\frac{[\sin\theta_{air}\,(CA)]}{v_{air}} = \frac{[\sin\theta_{glass}\,(CA)]}{v_{glass}}$$

   $$\frac{\sin\theta_{air}}{v_{air}} = \frac{\sin\theta_{glass}}{v_{glass}}$$

$$\frac{v_{air}}{v_{glass}} = \frac{\sin \theta_{air}}{\sin \theta_{glass}} \qquad \text{Equation 4}$$

- Snell's Law for the angle at the air-glass boundary would be written as follows.

$$\frac{\sin \theta_{air}}{\sin \theta_{glass}} = \frac{n_{glass}}{n_{air}} \qquad \text{Equation 5}$$

- Combining Equations 4 and 5 yields Snell's law for the speed in each medium.

$$\frac{v_{air}}{v_{glass}} = \frac{n_{glass}}{n_{air}}$$

- The same procedure could be used for any two media. Writing the equation in more general terms would result in this equation.

$$\frac{v_1}{v_2} = \frac{n_2}{n_1}$$

Section 3: Activity 1

1.

Angles (°)	Distance (cm)
$\theta_i =$ 26°	$d_o =$ 3.8
$\theta_r =$ 26°	$d_i =$ 3.8

2. This question is answered on the previous chart.
3. This question is answered on the previous chart.
4. The image was virtual.
5. Yes, the image is the same size.
6. The image is right-side-up.
7. Yes, these distances are the same.
8. Yes, it is horizontally reversed. Place a mark on one side of the pin head with a marking pen. The image will appear to have the mark on the other side.
9. The image was virtual because there was no light actually coming from behind the mirror.

10. They are formed by the converging virtual rays produced when real light rays from the object reflect from a mirror.

11. You could have listed the following five properties of the image.

- virtual
- right-side-up
- same size
- same distance
- horizontally reversed

12. a. Yes, the image is virtual, since no light actually comes from the image behind the mirror.

    b. Yes, the image is the same size.

    c. The image is right-side-up.

    d. The distances are the same.

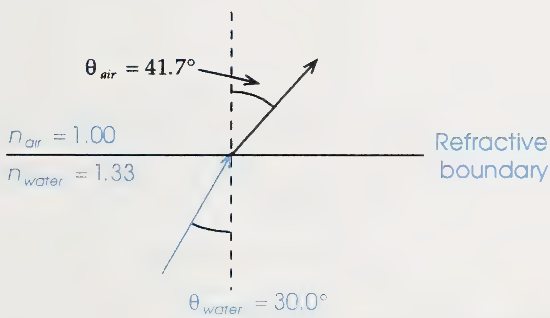
    e. The image is horizontally reversed, because if you are wearing a shirt with printing on it, the letters are all reversed. Refer to the photograph in the section introduction.

13. The image is also reversed front to back. You may be facing north, but your image is facing south.

14. Since $\theta_i = \theta_r$, you need a mirror that is exactly half your height to see yourself entirely. Figure 18-3a on page 369 of your textbook shows this clearly.

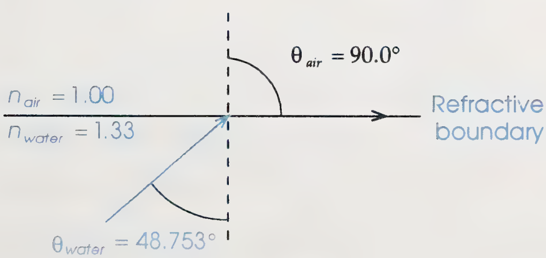
Section 3: Activity 2

1. a.



b. The angle in the air should increase, since the light ray speeds up and bends away from the normal.

2. a.



$$\frac{n_{air}}{n_{water}} = \frac{\sin\theta_{water}}{\sin\theta_{air}}$$

$$\sin\theta_{air} = \frac{(\sin\theta_{water})(n_{water})}{\sin\theta_{air}}$$

$$= \frac{(\sin 48.753°)(1.33)}{1.00}$$

$$= 89.8°$$

b. The refracted ray of light will travel along the surface.

3. No more refraction can occur. The beam simply reflects back into the water.

4. The angle in water that causes the angle in air to be 90° is called the critical angle.

5. a. The effect is called total internal reflection.

   b. Total internal reflection can only occur when light passes from a medium of high density into a medium of low density.

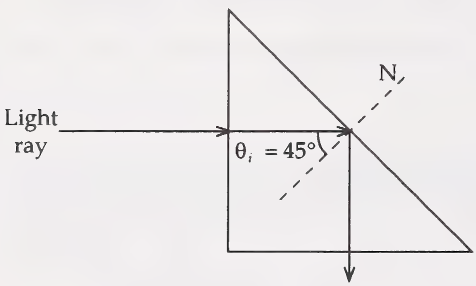
6. $\sin\theta_{critical} = \dfrac{n_2}{n_1}$

$$= \frac{1.00}{1.55}$$

$$\theta_{critical} = 40.2°$$

7. The light passes straight into the glass at face 1 without bending.

8.



9. a. 45°

   b. 40.2°

   c. Yes, the incident angle is greater.

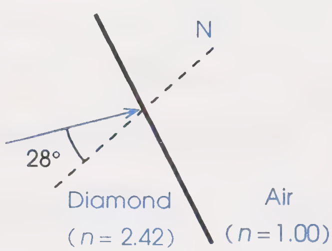
   d. Total internal reflection occurs at face 2.

   e. This is answered on the previous diagram.

   f. The ray will hit face 3 with a 90° angle or at 0° to the normal.

   g. The ray will pass straight through.

10. a.



$\theta_{diamond} = 28°$

$\theta_{air} = ?$

$$\frac{\sin\theta_{air}}{\sin\theta_{diamond}} = \frac{n_{diamond}}{n_{air}}$$

$$\sin\theta_{air} = \frac{(n_{diamond})(\sin\theta_{diamond})}{n_{air}}$$

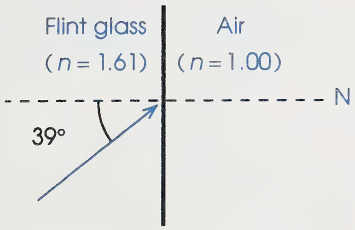
$$= \frac{(2.42)(\sin 28°)}{1.00}$$

$$\sin\theta_{air} = 1.14$$

$$\theta_{air} = \text{undefined}$$

Total internal reflection occurs.

b.



$\theta_{flint\ glass} = 39°$

$\theta_{air} = ?$

$$\frac{\sin\theta_{air}}{\sin\theta_{flint\ glass}} = \frac{n_{flint\ glass}}{n_{air}}$$

$$\sin\theta_{air} = \frac{(n_{flint\ glass})(\sin\theta_{flint\ glass})}{n_{air}}$$

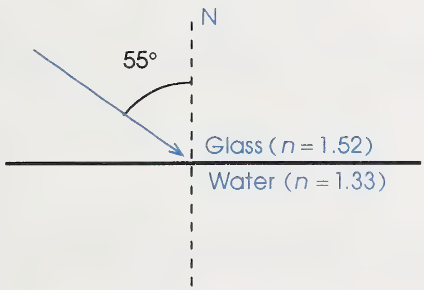
$$= \frac{(1.61)(\sin 39°)}{1.00}$$

$$\sin\theta_{air} = 1.01$$

$$\theta_{air} = \text{undefined}$$

Total internal reflection occurs.

c.



$\theta_{glass} = 55°$

$\theta_{water} = ?$

$$\frac{\sin\theta_{glass}}{\sin\theta_{water}} = \frac{n_{water}}{n_{glass}}$$

$$\sin\theta_{water} = \frac{(n_{glass})(\sin\theta_{glass})}{n_{water}}$$

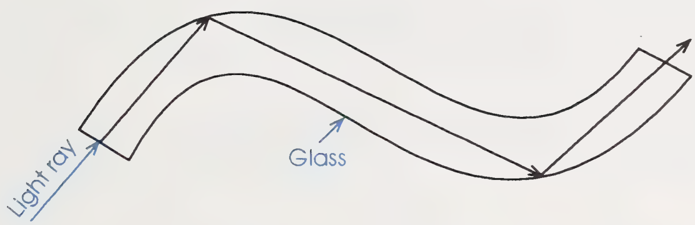
$$= \frac{(1.52)(\sin 55°)}{1.33}$$

$$\sin\theta_{water} = 0.9362$$

$$\theta_{water} = 69.4°$$

The light passes into the water. Total internal reflection does not occur.

11. a.



b. Yes, light could be transmitted over great distances through this tubing if little light energy was lost at each reflection.

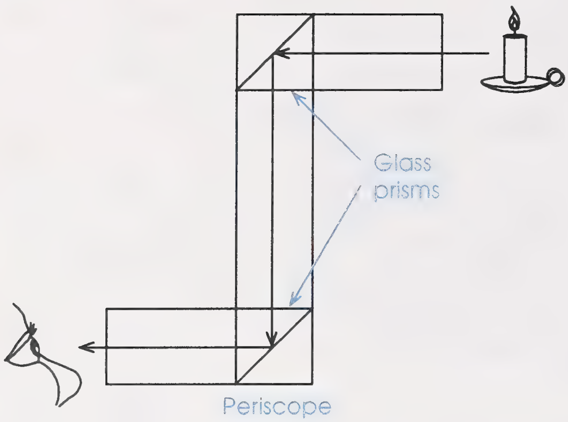
12. a. It is transmitted by varying the amplitude of the electromagnetic signal.

b. Light can be transmitted inside optical fibre. The electromagnetic signal is converted to a digital signal of pulsed laser light.

c. More information can be carried in optical fibre with greater clarity.

d. Optical fibres can be used in telecommunications, medicine, and science.

13.



14. The illuminating bundle sends light to the stomach. This insures that the light can reflect from the stomach wall and then be detected by the objective lens and transmitted by the ordered bundle.

Section 3: Activity 3

1. A puddle of water appears on the highway.

2. The two mediums are hot air on the surface which is heated by sun (n = 1.000 26) and cooler air above the surface (n = 1.000 28).

3. Light travelling into a less dense medium refracts away from the normal.

4. No. It is really an image of the blue sky.

5. Light was travelling into a medium with lower density (air).

6. Reach deeper and nearer to yourself in the water.

7. • Universal wave equation applied to light:

$$c = \lambda f$$

• Snell's law:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

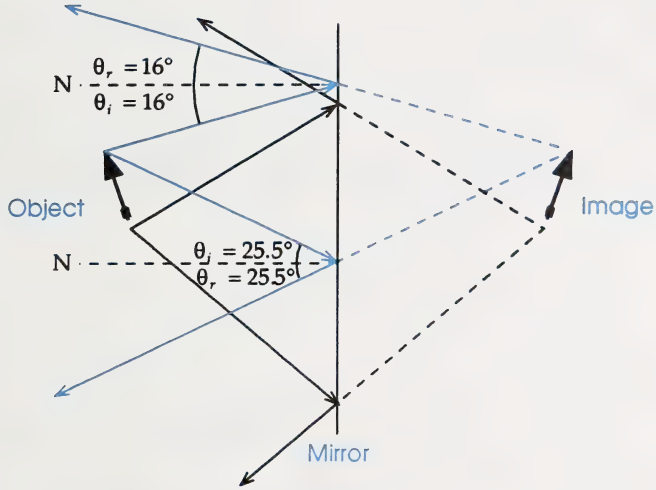
• Critical Angle (a special case of Snell's law):

$$\sin \theta_{critical} = \frac{n_2}{n_1}, \text{ where } n_2 < n_1$$

Section 3: Follow-up Activities

Extra Help

1. a.



b. The light rays behind the mirror are drawn as dashed lines because they are not really there. These rays are virtual because they only appear to originate from behind the mirror.

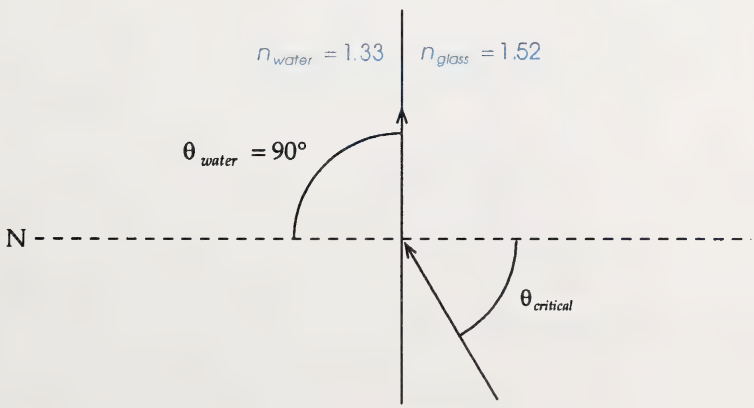
c. This question is answered on the previous diagram.

d. This question is answered on the previous diagram.

e. The arrow is drawn on the previous diagram. The object arrow is 17 mm long, while the image of the arrow is 16 mm long. Within measuring errors, it can be said that these objects are the same size and shape.

2. a. To produce a critical angle, the light must travel from the medium with the higher density (the glass).

b. This question is answered on the diagram.



c. $\theta_{water} = 90°$

$\theta_{glass} = \theta_{critical} = ?$

$n_{water} = 1.33$

$n_{glass} = 1.52$

$$\frac{\sin\theta_{glass}}{\sin\theta_{water}} = \frac{n_{water}}{n_{glass}}$$

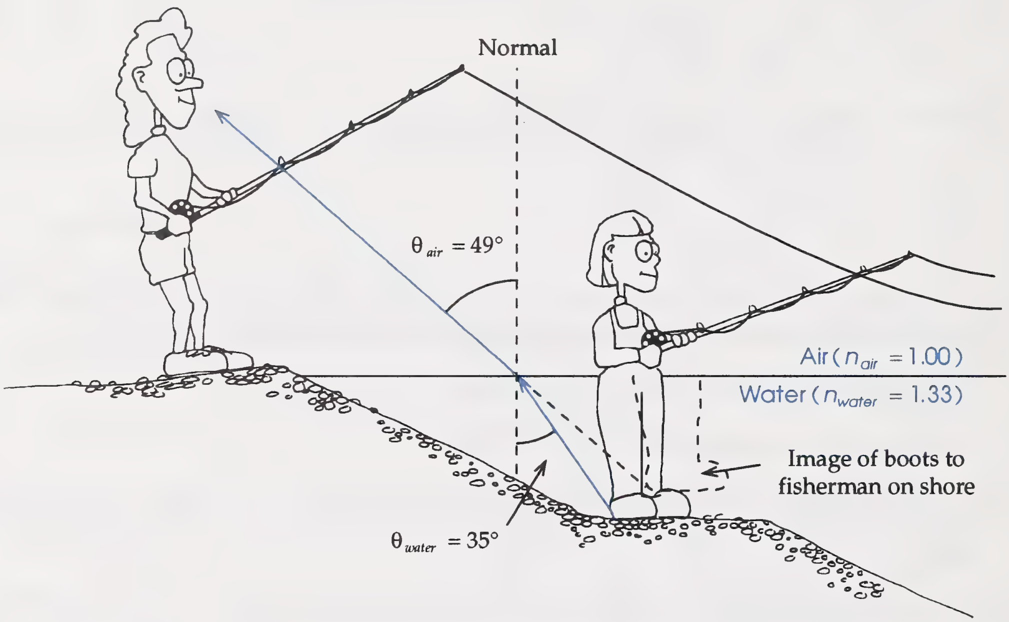
$$\frac{\sin\theta_{critical}}{\sin 90°} = \frac{1.33}{1.52}$$

$$\sin\theta_{critical} = 0.870$$

$$\theta_{critical} = 60.7°$$

d. The critical angle is the last possible angle in the more dense medium that will cause the light ray to refract in the less dense medium. Any angle larger than this will cause total internal reflection.

3. a.



b. If the measurements on the diagram are accurate, it should be possible to get the same value for θ_{water} (or any other variable) through calculation.

$\theta_{air} = 50°$

$n_{air} = 1.00$

$n_{water} = 1.33$

$\theta_{water} = ?$

$$\frac{\sin\theta_{water}}{\sin\theta_{air}} = \frac{n_{air}}{n_{water}}$$

$$\sin\theta_{water} = \frac{n_{air}}{n_{water}}(\sin\theta_{air})$$

$$= \frac{1.00}{1.33}(\sin 49°)$$

$$= 0.5675$$

$$\theta_{water} = 35°$$

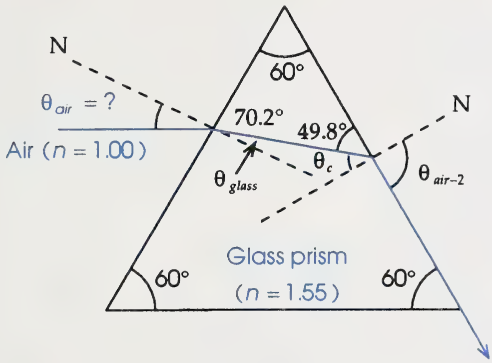
c. This question is answered on the previous diagram.

d. The fisherman in the water will appear shorter and disconnected from her legs.

Enrichment

1. The answers to this question can be found in the Critical Thinking Booklet.

2.



- If θ_{air-2} is 90.0°, the corresponding angle in glass must be the critical angle for glass. Solve for the critical angle first.

$n_{glass} = 1.55$

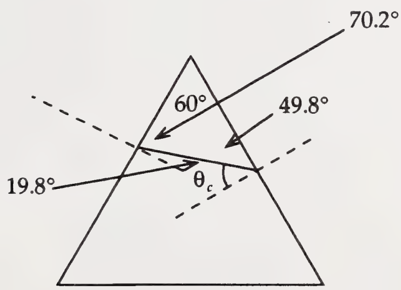
$n_{air} = 1.00$

$\theta_{air-2} = 90°$

$$\sin\theta_c = \frac{n_r}{n_i} = \frac{1.00}{1.55}$$

$$\theta_c = 40.2°$$

- Using θ_c and the fact that the angles of a triangle sum to 180°, solve for θ_{glass}.



- Now solve for θ_{air}.

$\theta_{glass} = 19.8°$

$n_{air} = 1.00$

$n_{glass} = 1.55$

$\theta_{air} = ?$

$$\frac{\sin\theta_{air}}{\sin\theta_{glass}} = \frac{n_{glass}}{n_{air}}$$

$$\sin\theta_{air} = \frac{(n_{glass})(\sin\theta_{glass})}{n_{air}} = \frac{(1.55)(\sin 19.8°)}{(1.00)}$$

$$\theta_{air} = 31.7°$$

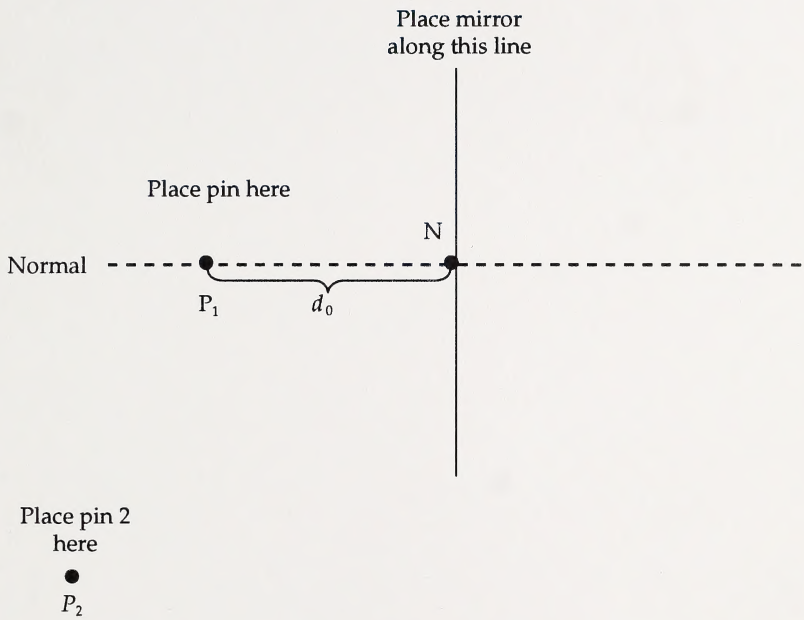
Section 2: Activity 1 Investigation: Light Travels from Air into Glass

Polar graph paper showing D-dish and pin locations

Section 2: Activity 1 Investigation: Light Travels from Glass into Air

Polar graph paper showing D-dish and pin locations

Layout page showing mirror and pin locations



Physics 20

Student Module Booklet
Module 6

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